Discussion with Dr. Hendryx
Calendar Entry

Wed 08/17/2011 4:00 PM - 5:00 PM

Location: EPA West 7114 Pacific Conference Line: [redacted] Conference Code: [redacted]

Rooms: 7114M-Pacific/DC-CCW-OWOW@EPA

Required:	Brian Topping/DC/USEPA/US@EPA, Damaris Christensen/DC/USEPA/US@EPA, David Evans/DC/USEPA/US@EPA, Marcel Tchaou/DC/USEPA/US@EPA, mhendryx@hsc.wvu.edu, Rose Kwok/DC/USEPA/US@EPA, Ross Geredien/DC/USEPA/US@EPA, Timothy
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Description

Update and follow-up from last discussion with EPA Office of Water

FOIA

Ross Geredien to: Christopher Hunter 11/18/2011 10:24 AM

My communication with Dr. Hendryx.

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----- Forwarded by Ross Geredien/DC/USEPA/US on 11/18/2011 10:15 AM -----

From: Ross Geredien/DC/USEPA/US
To: mhendryx@hsc.wvu.edu
Date: 08/18/2011 11:22 AM
Subject: Additional Health Papers

Dr. Hendryx,

It was great to speak with you on the Conference Call yesterday. I am attaching two peer-reviewed papers that I think you will find very interesting with respect to health effects from mining in Appalachia. These two papers are not typical epi studies, but they help fill an important gap in the health literature. The Blakeney paper is very unique in that it documents a number of psycho-social and occupational effects, incorporating anecdotal evidence using social survey methods. The Wigginton paper points to possible vectors of exposure that have not been discussed. And although I'm sure you have it already, I've attached Ben Stout's 2004 report.

wju_report Ben Stoudt 2004.pdf Blakeney and Marshall 2009.pdf

Wigginton et al 2007 Heavy Metals Water Tanks.pdf

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Water Quality, Health, and Human Occupations

Anne B. Blakeney and Amy Marshall

KEY WORDS
- environment
- health services research
- human activities
- rural health
- water

OBJECTIVE. To introduce evidence of the critical link between water quality and human occupations.

METHOD. A participatory action research design was used to complete a three-phase project. Phase 1 included mapping the watershed of Letcher County, Kentucky. Phase 2 consisted of surveying 122 Letcher County health professionals. Phase 3, the primary focus of this article, consisted of interviews with Letcher County adults regarding their lived experiences with water. The *Occupational Therapy Practice Framework: Domain and Process* (American Occupational Therapy Association, 2002) was used to structure questions. The Model of Occupational Justice provided the theoretical framework for presentation of the results.

RESULTS. The watershed in Letcher County, Kentucky, is polluted as a result of specific coal mining practices and a lack of adequate infrastructure. As a result, citizens experience occupational injustice in the forms of occupational imbalance, occupational deprivation, and occupational alienation.

Blakeney, A. B., & Marshall, A. (2009). Water quality, health, and human occupations. *American Journal of Occupational Therapy, 63,* 46–57.

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Most U.S. occupational therapy practitioners probably take clean water for granted, but many people cannot make this assumption. Approximately 1.1 billion people worldwide do not have access to clean, safe drinking water (Mintz, Bartram, Lochery, & Wegelin, 2001). In 1998, water-related diseases were responsible for 3 to 4 million deaths around the world (World Health Organization [WHO], 1999). In rural states, difficulties in gaining access to clean water are surprisingly common. In a recent survey of 384 rural health care providers across the nation, groundwater pollution and surface water contamination were the top two health concerns (Robson & Schneider, 2001).

WHO (2001) defined *health* as a dynamic interaction between person and environment; that is, health is the ability to participate in meaningful activities within the contexts of everyday life. This is similar to the *Occupational Therapy Practice Framework: Domain and Process* (American Occupational Therapy Association [AOTA], 2002), which directs occupational therapy practitioners to assess the contexts in which people perform their human occupations, including the physical, cultural, social, personal, spiritual, temporal, and virtual contexts.

Healthy People 2010 (U.S. Department of Health and Human Services, 2000) and the *Ottawa Charter for Health Promotion* (WHO, 1986) specifically identify environmental factors as critical for human health, noting that disturbances in the natural environment can affect one's ability to function. Although the international occupational therapy literature has acknowledged to some extent the natural environment's effect on human occupations (Cox, 1995; Peachey-Hill & Law, 2000; Rozario, 1997; Whiteford, 2000; Wilcock, 1998), within the U.S. occupational therapy literature is a notable absence of information addressing the connection among clean water, health, and one's ability to carry out necessary or desired human occupations. Geographical terrain, first included in the category of physical context in the *Uniform Terminology for Occupational Therapy* (AOTA, 1994), is rarely acknowledged, despite its consideration as "an overarching, underlying, embedded influence on the process of service delivery" (AOTA, 2002, p. 614).

Social Justice

Social justice has been defined in multiple ways. For example, *distributive justice* refers to the needs-based allocation of resources (Rawls, 1971), whereas *procedural justice* is concerned with a participatory decision-making process (Lind & Tyler, 1988). The justice of difference described by Young (1990) critically examined the social institutions that perpetuate disparities. Despite these differences in definitions, most researchers would agree that a socially just society is one in which all persons have equal rights, opportunities, access to resources, and protections. Occupational therapy practitioners have traditionally been advocates for social justice, beginning with Eleanor Clarke Slagle, who focused on the social, economic, and health issues of Chicago's marginalized immigrant residents at Hull House in the early 1900s (Kramer, Hinojosa, & Royeen, 2003; Quiroga, 1995).

An essential principle of social justice is that disadvantage results from multiple causes: poverty, lack of education, and polluted environments, to name a few. Generally, "inequalities beget other inequalities," which is why, for example, already disadvantaged people suffer disproportionately from environmental health hazards (Gostin, 2007, p. 3). Historically, ethnic-minority and working-class European-American communities have been chosen for noxious industries that are unwanted elsewhere, causing further health inequalities for those populaces (Bullard, 2000; Cutter, Holm, & Clark, 1996; Schlosberg, 1999; Taylor, 2000). The current large-scale strip-mining operations in Appalachia take place in rural mountain communities. This is an example of environmental injustice in which an industry requires a population to sacrifice the physical environment surrounding their homes. After large-scale explosions in mountaintop removal mining, land is destroyed and water becomes polluted with heavy metal by-products of the mining process. People then become ill as a result of specific coal-mining methods and a lack of industry regulation (Montrie, 2003).

Occupational Justice

Occupational justice is an emerging concept in the occupational therapy literature. Essentially, occupational justice rests on two important principles: (1) the belief that occupational participation is a determinant of health and (2) the principle of "empowerment through occupation" (Townsend & Wilcock, 2003, p. 257). Both of these concepts inform occupational therapy practice.

An occupationally just society enables access to both opportunities and resources necessary for carrying out human occupations. It ensures participation in occupations by all people regardless of differences in abilities that may result from biology or human interaction with the environment (Townsend & Wilcock, 2003). An occupationally just society is one in which people flourish by doing what is useful and meaningful to themselves and their communities. A society can experience either opportunities, in the form of occupational justice, or restrictions, in the form of occupational injustice.

Occupational deprivation is one result of occupational injustice. It occurs when "a person or group of people are unable to do what is necessary and meaningful in their lives because of external restrictions" such as environmental barriers or lack of access to needed resources (Whiteford, 2000, p. 200). According to Wilcock (1998), these external forces may include poverty, cultural values, lack of employment opportunities, illness, or disability (p. 149). Whiteford (2000) suggested that a lack of ecological sustainability might also lead to occupational deprivation.

Another outcome of occupational injustice is *occupational alienation,* a consequence of experiencing life as meaningless or purposeless (Townsend & Wilcock, 2003). For example, if human beings are reduced to doing repetitive tasks without meaning or dignity as societies become increasingly industrialized, occupational alienation can occur (Rozario, 1997). People who experience occupational alienation feel as if they are doing the same things repeatedly with little hope of change or improvement in their lives.

A third outcome of occupational injustice is *occupational imbalance.* It is based on the belief that health requires a balance between work, leisure, and rest. Without this balance, illness, burnout, or boredom often results (Wilcock, 1998). Occupational imbalance is unjust when opportunities for different types of occupational experiences differ between the "haves and the have-nots" (Wilcock, 1998, p. 144).

Kronenberg and Pollard (2005) expanded the notion of occupational injustice by developing the concept of occupational apartheid. This terminology was deliberately chosen to confront and expose the often collusive political and economic forces behind occupationally unjust circumstances. *Occupational apartheid* is defined as "chronic established environmental conditions that deny marginalized people rightful access to participate in occupations that they value as useful and meaningful" (Kronenberg & Pollard, 2005, p. 65). The concept of occupational apartheid acknowledges that there are systematic inequalities based on characteristics such as race, religion, gender, ethnicity, or social status.

Occupational injustices occur as a result of the conditions of occupational apartheid. These conditions are perpetuated both intentionally and unintentionally by power elites as a way of maintaining privilege (Kronenberg & Pollard, 2005).

The concept of occupational apartheid goes further. It not only uncovers inequalities in occupational opportunity but also obliges people to confront these realities. An awareness of occupational apartheid requires action to begin the process of analysis and a sustained program of collaboration to create substantial change. This is especially true for occupational therapy practitioners, whose professional responsibility is to ensure occupational well-being. Ultimately, occupational therapy practitioners must account for our actions because, as health professionals, we are included in the "roll-call of agents of social control" (Kronenberg & Pollard, 2005, p. 69).

This study focused on the connection between human occupations and the physical environment in the Appalachian Mountains of Kentucky. Theoretically, it was informed by concepts from social and environmental justice and the Model of Occupational Justice (Townsend & Wilcock, 2003). The purpose was to introduce evidence of the critical link between clean water, an essential natural resource, and the ability of people to carry out both necessary and desired human occupations.

Study Context: Letcher County, Kentucky

Located in the Appalachian coalfields of eastern Kentucky, Letcher County provides the physical, cultural, and social contexts for this study. When coal mining began in the 1880s, water was among the first natural resources to be damaged (Dykeman, 1974; Eller, 1982). With the advent of surface mining (i.e., strip mining) in the 1950s, environmental degradation reached staggering proportions throughout the Appalachian coalfields (Montrie, 2003; Spadaro, 2005).

Mountaintop removal is a relatively recent method of strip mining in which the tops of mountains are literally blasted away to reveal the low-sulfur coal seams that lie directly below. Although underground mining produced limited damage to the environment, the current method of mountaintop removal is the most environmentally destructive form of coal mining. It is currently permitted to allow coal to be produced as quickly and cheaply as possible. The following is a description of the process of mountaintop removal:

> Coal companies first . . . scrape away the topsoil. . . . Next, they blast up to 800 feet off mountaintops, with explosives up to 100 times as strong as the ones that tore open the Oklahoma City Federal Building. Giant machines then scoop out the layers of coal, dumping millions of tons of "overburden"—the former mountaintops—into narrow adjacent valleys, thereby creating valley fills. . . . Mountaintop removal generates huge amounts of waste. While the solid waste becomes valley fills, liquid waste is stored in massive . . . coal slurry impoundments, often built in the headwaters of a watershed. (Ohio Valley Environmental Coalition, n.d., p. 1)

In Kentucky, there are currently 88 of these dangerous coal slurry impoundments. Twenty of these impoundments are ranked as high risk for breakthrough potential (Cole & Seigel, 2001). There is a history of such impoundment breakages in Appalachia. In 1972, a coal slurry impoundment owned by the Pittston Coal Company collapsed under its own weight. When it broke, 132 million gallons of toxic coal waste spilled into Buffalo Creek, completely demolishing several towns, leaving more than 4,000 people homeless, and killing 125 people (Erikson, 1976).

In October 2000, another coal slurry impoundment broke in Martin County, Kentucky. Although no one was killed, 300 million gallons of thick, black, toxic slurry were released into the local watershed, affecting approximately 100 miles of waterways and surrounding land (McSpirit, Hardesty, & Welch, 2002; Mueller, 2000). To place this in perspective, the Exxon Valdez disaster spilled 11 million gallons of crude oil in Prince William Sound, Alaska (U.S. Environmental Protection Agency [EPA], n.d.). In the Martin County sludge spill, public and private water supplies for more than 27,000 people were polluted (Spadaro, 2005). Massey Energy, the company responsible for the spill, was ultimately fined in federal court a mere $5,500 for what was the largest manmade environmental disaster in the history of the southeastern United States (EPA, n.d.; Lovan, 2004). Between mid-December 2003 and late January 2004, five such blackwater spills from slurry impoundments polluted eastern Kentucky streams (Alford, 2004).

Located near Martin County is Letcher County, Kentucky, home of the headwaters of the Kentucky River. Situated deep within the Appalachian coalfields, Letcher County is the site of several active coal-mining operations that infuse chemical by-products, runoff, and silt into the Kentucky River. This has contributed to a "no bodily contact advisory" for 86 miles of the North Fork of the Kentucky River in Letcher County (Kentucky Department for Environmental Protection, 2004). As Letcher County residents repeatedly say, no water runs into Letcher County; it all runs out. Thus, the pollutants that enter the Kentucky River Basin in Letcher County have an impact on the water as it flows downstream. Approximately 710,000 people live in the Kentucky River Basin and rely on it for their drinking water (Kentucky Division of Water, 1997). However, this watershed no longer provides safe water for many Kentuckians. In fact, the EPA has designated 633 miles of the Kentucky River Basin to be unsafe for human use of any kind (Cole & Siegel, 2001).

Although the goal of Letcher County's local government is to provide everyone with access to water from the municipal water system, currently this system serves approximately one-third of the county's 25,277 residents. This municipal water system draws water from the Kentucky River, transfers it into two water treatment plants in an effort to clean it, and redistributes it to county residents. Two-thirds of households and businesses in Letcher County must rely on wells for their water. Many of these private wells are not routinely tested or properly maintained, posing a potential risk for those who rely on them (Banks, Jones, & Blakeney, 2002; Marshall, 2004).

Many county residents report having had good, clean water in the past, only to have it destroyed by the blasting that occurs as part of strip mining (Marshall, 2004). When blasts are set off as part of the mining process, underground aquifers are often cracked and then contaminated, allowing oil, gas, and sediment to enter the wells served by that aquifer. When this occurs, well water is permanently polluted. At other times, the water runs out of the cracked aquifers and wells run dry. At that point, the only option is to drill another well in hopes of tapping into another underground aquifer, which may or may not be polluted by the mining process (Banks, Jones, & Blakeney, 2002, 2005).

In 2001, members of the Letcher County local government and the Community Action Team requested a partnership with the Center for Appalachian Studies at Eastern Kentucky University (EKU). The county's citizens had set a goal to clean up their water by 2012. Swamped with an overwhelming amount of data about levels of pollutants in their watershed and an uncertainty about how to analyze this data, the county asked EKU for help. The EKU Center for Appalachian Studies agreed to partner with Letcher County in a multiphase research project called the Headwaters Project (Banks et al., 2002, 2005).

Method

Participatory action research (PAR) provided the philosophical and methodological framework for the Headwaters Project (Banks et al., 2002; McTaggart, 1991; Park, 1993; Reason, 1994; Whyte, Greenwood, & Lazes, 1991). In PAR, a problematic issue originating in a community or organization is examined from the perspectives of those most affected by it (Brown & Tandon, 1983; Fals Borda, 1991; Freire, 1970). The egalitarian approach between researcher and participants is intended to break down the barriers of traditional positivistic research so that the participants may develop, take ownership of, and effectively use the emerging knowledge without fear of exploitation from outside interests (McTaggert, 1991).

No one set of PAR practices is applicable or appropriate to all studies (Israel et al., 2003). There are varying degrees of control by researchers. Stoecker (2003) designated three different roles of the participatory action researcher: the collaborator, initiator, and consultant. In all PAR, it is vital to have fully collaborative roles between researcher and participants in the development of the research question, in setting the research priorities, and in deciding how the results of the study will be used. Whatever role the researcher takes, the resulting action is the most important (Stoecker, 2003).

In the Headwaters Project, university faculty and students served as consultants, as requested by community residents. The research priorities and questions were generated by the community, with the analysis and theoretical application designated to faculty with student assistance, as appropriate. Ultimately, the county government decided on the use of the results (as described later).

In both occupational therapy and PAR, clients are actively involved in planning and evaluating what is important for them to accomplish. Recently, occupational therapists have begun to consider PAR to be a viable research tool for the profession (Letts, 2003). As the complexity of health care increases, so too does the need for research tools that can adequately handle the ramifications (Taylor, Braveman, & Hammel, 2004).

A Letcher County Citizens' Advisory Committee was formed to represent the county in negotiating the research process with EKU faculty and students. The committee was made up of adults who represented various segments of the county and included the county judge–executive, the chief elected official in the county; a local filmmaker; the owner of a restaurant; the head of the Letcher County Action Team, a volunteer citizens' organization addressing local issues; an attorney who was a former member of the local water district; a rural grocery store owner; a retired schoolteacher; the director of a rural community center serving low-income children and adults; and the local organizer for Kentuckians for the Commonwealth (KFTC), a statewide citizens' organization that routinely engages in civic activities. Ascribing to the PAR process, the citizens' advisory committee collaborated with faculty and students for 2 years (2001–2002). The advisory committee provided input and had the ultimate approval for each method of data collection as the project emerged.

Headwaters Project, Phases 1 and 2

Phase 1 of the Headwaters Project was conducted in the fall of 2001 under the leadership of EKU geography and sociology faculty. Phase 1 focused on translating water quality data into meaningful information. This was accomplished by developing bar graphs from tables of existing data and mapping the watershed of the entire county. Using available data from federal, state, and local resources and application of the geographic information system, students and faculty developed maps that clearly demonstrated the location and degree of various pollutants in the water, such as toxic metals from local coal-mining operations, total suspended solids, sulfates, iron, and bacteria (such as fecal coliform) from absent or failed septic systems. They also plotted the pH levels and the dissolved oxygen in the water, both critical indicators of healthy aquatic systems (Banks et al., 2002).

The results of the mapping project allowed county residents to see where pollutants were entering the water and the relationship of these pollutants to recent mining permits, ongoing coal-mining operations, and the lack of an adequate countywide infrastructure to handle solid waste and sewage. For example, the maps specifically identified the number and location of straight pipes that take waste (including sewage) directly from households and businesses and dump it into local streams that eventually flow into the Kentucky River, the county's source for the municipal water system. Straight pipes remain a problem throughout the Appalachian coalfields because historically many coal-mining companies built homes for miners without providing for an adequate infrastructure to handle water and sewage needs (Banks et al., 2002). Now armed with usable information, citizens and students wondered whether the water was connected to illnesses and whether local health professionals shared their concerns.

Phase 2 of the project emerged as a result of discovering elevated levels of contaminants, such as bacteria and heavy metals, in the county's watershed. This part of the project was carried out under the direction of sociology faculty. The citizens' advisory committee collaborated with students to develop a survey and a list of agencies employing health professionals throughout the county. Students then surveyed 122 health professionals, primarily physicians and nurses, to explore their beliefs and practices concerning local water quality and its impact on the health of the county's citizens. Seventy-three surveys were returned (60% response rate).

The surveys revealed that the majority of health professionals in the county agreed that (1) water quality was a serious health issue for the county's residents (87% of respondents), (2) current water treatment practices for the municipal water system were not effective in removing pollutants from the Kentucky River (69% of respondents), (3) patients were regularly directed to use bottled water (62% of respondents), and (4) specific ailments were directly related to environmental problems (77% of respondents; Banks et al., 2002).

The survey results support data collected by the EPA in 2001 (EPA, 2001), which revealed that four inorganic chemicals were present in the public drinking water system in Letcher County: cadmium, thallium, nitrates, and antimony. Short-term health effects of exposure to these chemicals include nausea, cramps, diarrhea, vomiting, liver and kidney damage, shortness of breath, shock and convulsions, and nerve damage. Long-term effects may include liver, kidney, or spleen failure; bone damage; and cancers, particularly those of the digestive system (EPA, 2001, cited in Banks et al., 2002, p. 39). In open-ended questions on the surveys, health professionals reported seeing a high incidence of patients with nausea, cramps, diarrhea, bladder and kidney infections, gastritis, and increased rates of cancer. They attributed the increased rate of these conditions to the county's poor water quality. However, when students searched for corroborating evidence in state health data, they were unable to locate any correlation between water quality and the health of county residents.

Students shared the maps and the survey results with Letcher County residents in a public forum in the spring of 2002. Enlarged maps mounted on poster board were also left in the county action team's office on Main Street in the county seat. During the open discussion, local citizens expressed astonishment and anger that state public health agencies had not established a link between local water quality and the health of county residents. They believed that the water caused many people to become ill, just as the survey revealed these same beliefs among health professionals. As a result, the citizens' advisory committee requested a listening project in which students would interview local people about their water and their health to document directly their lived experiences.

Headwaters Project, Phase 3

To respond to this request, Phase 3 of the Headwaters Project was conducted in the fall of 2002. Fourteen students (graduate and undergraduate) enrolled in Providing Health Services in Appalachia, an occupational therapy course for majors and nonmajors. The course was redesigned as a field research project for one semester. Students were trained in interview techniques and in transcribing, coding, and analyzing qualitative interviews. They were then divided into seven teams of two people each. Over 3 nonconsecutive weekends, students and faculty traveled to Letcher County and interviewed a total of 40 adults (18 years or older), including 23 men and 17 women. The *Framework* (AOTA,

2002) and the results of Phases 1 and 2 of the project were used to identify the topics to be discussed. Specifically from the *Framework,* activities of daily living, instrumental activities of daily living, routines, and activity demands were investigated. The citizens' advisory committee also gave input regarding the questions, offered space to conduct the interviews, and subsequently approved the interview format.

Interviews were conducted in the homes of participants or in public meeting places, such as the public library, the action team office, rural grocery stores, or a local community center. Interviewees determined the location of the interviews. The interviews followed a semistructured format that included closed- and open-ended questions and lasted 1–3 hr. All interviews were tape recorded. All participants signed an informed consent form and were given a copy of the form to keep.

Student interviewers began with the open-ended statement: "Tell me about your water." Students were taught to probe for follow-up information (Babbie, 2000), and some examples were provided on the interview guide (see Figure 1). Because the results of Phase 1 and Phase 2 of the Headwaters Project were used to develop the interview guide, interview questions reflected the belief that citizens experienced problems with their water. However, students were instructed to encourage expression of all information reported by the participants, including satisfaction with the county's water.

Participant Selection

The interviews had to be arranged from the EKU campus during the weeks preceding the students' presence in Letcher County (3 hr away). A list of names and telephone numbers of potential interviewees was initially provided by the citizens' advisory committee. This initial list included adults who were predicted by the local advisory committee to be open to student interviewers and willing to discuss their water quality. Openness to student interviewers was based on former community involvement in the county, such as membership in parent–teacher organizations, service in local civic organizations (such as KFTC), and volunteering in church activities or community projects. From the initial list, a snowball sampling technique (Babbie, 2000) was used to generate names of potential participants.

By the end of October, students had transcribed 40 interviews verbatim, resulting in approximately 800 pages of transcribed material. We began independently coding and sorting the interviews manually and compared the results of this initial process to determine broad themes. We then individually recoded all 40 interviews for a more in-depth analysis. Brief memos were written to identify more specific themes that emerged within the data. We compared these themes to information on the physical context and to the areas of occupation as outlined in the *Framework* (AOTA, 2002; Marshall, 2004). Amy Marshall then recoded all 40 interviews a third time using the Ethnograph 5.0 software (Qualis Research, Colorado Springs, CO) for categorization and data retrieval purposes. This supported the establishment of an audit trail through development of a numerical list of coded items that represented recurring themes from all 40 transcripts.

Member checking of individual interviews was not possible because of the human subjects' protection requirement to destroy all identifying information once the interviews were transcribed. However, we and 5 students returned to the county for a week in the spring of 2003. During an annual cultural festival, students displayed the original maps of the county (from Phase 1) and shared the results of the transcribed interviews with approximately 100 adults. These people confirmed the patterns identified in the coded interviews, often adding their own accounts of similar problems in coping with polluted water or inadequate water supplies. During this week, we also visited with residents in public dining facilities, at local grocery stores and at a local radio station where students explained their current work on the air. We also met with the county judge–executive and the county's solid waste coordinator, who confirmed our findings.

Results

As we recoded the interviews, it appeared that almost every daily occupation as identified in the areas of occupation of the *Framework* was affected by polluted water in the physical environment (watershed), as well as inside the home from well water or the municipal water supply. In addition, several new daily activities emerged, including backwashing water filters, placing special salts and potassium in water filters, cleaning well pumps to discard sediment and debris, carrying clean water into homes, and tracking permits for new mining operations to be prepared to mount community resistance to threatened water supplies.

By using the *Framework* to help shape the interview questions, we asked people how their occupations routinely occurred and how their routines might have been altered because of their water. It became evident to us that exposure to polluted water, both in drinking water and in the physical environment in local streams, ponds, and lakes, created a situation of occupational injustice. Therefore, we adopted the Model of Occupational Justice as an organizing framework to present our findings. Our findings are organized and presented below as examples of occupational injustice.

1. **Tell me about your water.** Are you concerned about it? Do you see a problem with the water in Letcher County? If so, when do you think the problem began?
2. **Do you think there are pollutants (e.g., germs, bacteria, metals) in the Kentucky River?**
   Do you think that current water treatment methods remove these pollutants?
   If not, what kinds of things do you think stay in the water?
3. **What do you think caused the Kentucky River and local streams to be polluted?**
   Bad septic systems? Straight pipes? Pesticides? Natural gas extraction?
   Deep mining or strip mining that caused acid mine drainage?
   Contaminated underground water? Anything else?______________
4. **Where do you get your water?**
   City water? A well? A spring? Other? Do you live near a stream or other body of water?
   Do you buy bottled water? Do you buy water filters? If so, how often?
   About how much do you have to spend on water/filters each month?
   Do you do without other things so you can get clean water such as medicine? Food? Clothes? Other things?
5. **Do you think that your water is—**
   Safe for drinking right out of the tap? Safe for other things, like cooking? Bathing? Laundry?
6. **What has most changed in your life because of your water quality?**
7. **Are there activities in your daily routine that you have to do because of your water . . . any adjustments that you have to make?** For example, do you have to change the way you cook? You eat? Do your laundry? Your bathing? Cleaning? Gardening? Anything else?
8. **How about your leisure and recreation . . . does the water here limit—**
   Your fishing? Your swimming? Outdoor activities? What about children's outdoor play? Do you ever tell them to stay away from the water?
9. **How does the water affect your social activities . . . things you do with family? Or friends?**
10. **How do you think the water quality affects Letcher County: Tourism? Business?**
11. **Do you get frustrated because of the water?**
12. **Do you think that the water affects your health?**
    Do you ever get sick and think it might be the water causing it?
    Would you feel comfortable telling this to your doctor or nurse? If not, why?
13. **Does the doctor or a nurse ever tell you to buy bottled water?**
14. **Are you concerned about your family's health because of the water, especially any children? What about elderly family members?**
15. **Is there any *one particular thing* that you used to be able to do that you cannot do now because of the water?**
16. **Have you done anything you haven't already told me about to try to improve your water?**
17. **What is your BIGGEST WATER PROBLEM each day?** How do you adapt to this?
18. **Who or what is the biggest help to you in dealing with the water . . .**
    Your family or friends? A church? A community group? Any certain organization? Other?
19. **Is there any one thing that you think should be done to improve the water in your area?**
20. **Is there anything else that you want to say about your water?**
21. **Can you think of anyone else that we should talk to? (record names, phone numbers)**
22. **Demographics: Male/Female_____ Age:______ Number in household: ______**
    Ages in household:________ Access to a municipal water treatment system? ___Yes ___ No

Figure 1. Headwaters Project Water Quality Interview (with suggested probes; Blakeney & Marshall, 2002).

Occupational Imbalance

Letcher County residents described numerous limitations in their ability to perform personally desired occupations because they had to continually reorganize the temporal context of their daily routine to adapt to their poor water quality. "Everybody has to kind of plan ahead for water. . . . [I] go to my uncle's house because he has a good source of water . . . just to be able to boil an egg for dinner." The most common accommodations when preparing meals were to boil all water before cooking, use multiple water filters, or buy bottled water to cook with—sometimes 20 gallons per month. People described two stages of cleaning produce: First, the dirt particles are rinsed off with tap water; next, the impurities from the tap water must be rinsed off with bottled water. One person questioned,

> Washing produce has become a concern, because how do we wash the produce? We sometimes don't know [whether] to eat it without washing it, or to wash it. That is a real question for us. At this point we wash it at the sink and pray and hope that we are making the right decision.

Home maintenance routines are lengthened by the increased frequency and time people spend scrubbing off water stains from commodes, bathtubs, sinks, and carpets. "I'm continuously having to scrub the bathroom fixtures with whatever I can get to get [the stains] off with." One of the most common activities of daily living for Letcher County residents is washing water filters. "We have to . . . backwash the filter . . . every night." Although one man felt "satisfied" with his water and believed that he had "good water" at his home, he explained,

> We've got 3 wells, 4 pumps, 2 tanks, 12 filters. . . . Our water is good, after we got salt and potassium filters, and chlorinators . . . then we got just regular sediment filters. Just before it goes into the house . . . we have to prefilter it through two different filters.

The water also causes discoloration of clothing. One individual explained, "I learned to wash dark colors first, and then to do the light colors right after. Not even let it sit for a while. And I still lose clothes occasionally." Most respondents stated that they simply don't buy white clothing. "When I buy clothes, I can't buy white tee shirts, I have to buy colored tee shirts because my water is so bad." The laundromat is frequented often because its source of city water is less likely to stain clothes. "I have to go to the laundry mat . . . to keep my good clothes nice—if you don't want orange all over them."

Personal care is challenging for Letcher County residents as well, particularly bathing. One resident related, "I went to run water in the tub . . . it was first black, like off coal, and then it came out all rusty-looking. Well, you come out of the tub worse than when you went in." One individual reported being forced to buy a swimming pool filter for the bathtub because it was the only way to collect all the sediment. Some reported that they routinely add Clorox to their bathwater. Bottled water is frequently used for brushing teeth, as well as coloring or applying permanent waves to hair. A commercial product called Iron-Out, used to remove iron build-up from clothing, is applied by many residents to their hair.

Significant damage happens to homes as a result of blasting, which refers to explosives that are detonated during strip mining. For those who live close to an active mining site, the extreme noise, quaking, and vibration produced by the blasting are highly disruptive and dangerous, especially when their homes are hit with "fly rock" (i.e., flying boulders). One respondent recounted,

> I've been sitting there watching television and they'll blast and my windows will shake like they're coming out of the house and my chair will move around. . . . I've had my daughter sitting on a milk crate in my garden picking vegetables and the blast has almost knocked her off the milk crate.

Another said, "You cannot sleep in that holler [neighborhood] at night. . . . All you hear is boom, boom, boom, boom. . . . I mean, they are interrupting people's lives here."

The performance of many daily occupations such as these are filled with alterations of what many would consider to be typical routines, resulting in occupational imbalance. Recurring themes included the amount of time that people spent performing various occupations; the degree to which people reported changing or adapting their routines; the sequence and timing of their activities; and the impact of the physical environment on daily life.

> Everything in my life has changed: from life to death. That's what they're doing—they're putting us in the grave, really . . . . It's just worry, worry all the time. Sit and worry about the water, sit and worry about the bills. It's just completely changed our lives.

Occupational Deprivation

Letcher County residents also experience occupational injustice from being deprived of participating in valued occupations because of contaminated water. One prominent theme that emerged from the interviews was people's recollections of Letcher County before the strip mining. Because of the abundance of rivers and streams in this headwaters region, the water used to be a central part of people's daily lives. Residents recollected engaging in a wide variety of play and leisure occupations involving water. Swimming, wading, fishing, catching minnows and crawdads, boating, picnicking, and gardening were some of the favorite occupations mentioned by respondents. One resident recollected,

> A few years back, we'd take the kids and go out and have a good time, but now I'm just about afraid to let the kids get in the water because of the . . . pollution and stuff in there . . . 5 years ago it was a treat to get in your inner tube, load up your pickup and go down and spend a day at the beach . . . but the last few years . . . I won't take mine down there.

Another individual said,

> We used to picnic on the river a lot . . . we'd go to Cumberland or to Poor Fork for a swim. Everybody went to a place called Slick Rock. We would go camping, fishing . . . I wouldn't camp now if somebody held a gun on me.

Other than going to stocked ponds or nature preserves, there is little opportunity to fish. If people do fish, they typically throw them back: "I just pick them off and throw them back and let them go." Gardening is another occupation that has been affected. "We've got that little stream that runs by our house . . . I know it's polluted, and . . . some people say, 'Well, won't that damage your crop?' [The plants] are dying for lack of water already, and so I'm using that as a last resort."

Residents are deprived of engaging in their favorite leisure occupations because of safety concerns about the water. These occupations' significance lay not only in personal and cultural meaning to residents but also in their sustenance value. Potential income is lost for people who think it is no longer safe to sell produce from their gardens. Others have given up eating fish that they've caught locally, a common method of stretching limited food budgets. For a rural, economically depressed area such as Letcher County, these occupations are not easily replaced.

Occupational Alienation

The inability of residents to exercise choice or control over their daily occupations because of environmental destruction is a source of alienation. They expressed feelings of apprehension about going into public as a result of difficulty in maintaining their clothes and other personal items. This was obvious in statements such as, "You can imagine getting up to go to church on Sunday morning and go smelling like gasoline [due to pollutants in the water]" or "I pride myself on the way that I look when I go out in public . . . it makes you feel ashamed to have to go out with something that was bright and pretty, now yellow and dingy. You know, it begins to affect your self-esteem and things like that."

People are not only uncomfortable about going into public places but also feel self-conscious when family or friends visit their own homes. "When company comes from the city . . . they look at you, wondering why your bathroom is so skuzzy looking. . . . People come to your house and they're not used to seeing iron stains."

Respondents perceived a hierarchy of power relations. Despite its best efforts, the county government is left relatively powerless in the face of the corporate interests of the coal industry and the power it wields at state and national levels. Residents cited the leniency or lack of enforcement of laws, such as the Clean Water Act, which was created with the intent to hold industry accountable to environmental standards. Many such laws are so weak, mismanaged, or unenforced, however, that no one benefits from their original intent. Even conspicuous or widespread damage is ignored. One respondent stated,

> [The coal companies] dump diesel fuel over the mountain, it comes into the stream, down the creek it goes, and we got to deal with that, and they don't care if . . . sludge runs over in the creek or they push barrels of oil over there and it rolls down the creek . . . nobody worries about it.

Many residents feel, however, that they have no recourse against what is the only major industry in the county: "There are bad consequences when you buck the system. You know that any place you go. But right here in Letcher County, it's the worst in the world." Challenging a coal company may result in loss of jobs for family or friends.

At times, a sense of grief and alienation pervaded their statements: "People's spirit . . . has degraded . . . because of the degradation of the river . . . if you spend all that time being unable to combat it, sometimes you just kind of lose hope and join in and think that the river is unrecoverable." They expressed their belief that the coal industry has an unfulfilled responsibility to the public.

> Mining industries came in, they raped our land, stripped it, left it, and they left chemicals all around. It does not bother them because most of them that come and dig, they live in . . . other states. It does not bother them that these chemicals are left in the water.

One woman said,

> One day—this is the way I feel—I think the day will come when water will be more of a concern than coal. You can't drink the coal. But we do need water. That is a necessity of life. But these companies come in to make a fast dollar. They want to get it as fast as they can, and they would like for the people to shut their eyes, let them get the coal, and move on out. Then what do you have left? Nothing. Coal's gone. Lumber's gone. All you got left is a bunch of mud, and mountains are took off, and no water. I believe the day will come when water will be worth more than coal. We can do without the coal, but we can't do without the water. So that's the way I look at it. I got grandchildren coming up and I'd like to see them have some water and a place to live. That's about the way that I would sum it up: The water is worth more than the coal.

Letcher County residents, including local government officials, have virtually no trust in the coal-mining industry or in state and federal regulatory agencies. However, many local citizens are committed to challenging the industry through both individual and collective political action. Several people in the county developed new roles in the area of civic leadership: organizing members of their immediate neighborhoods to consider class action lawsuits against international coal corporations or organizing groups of citizens to travel to the state capital to lobby lawmakers in support of specific legislation. Some citizens also volunteered to give public testimony at legislative hearings. One woman was successful in securing a visit from a *New York Times* reporter who documented widespread environmental degradation, including water contamination, in her community.

Several social justice organizations in Letcher County provide support for people to confront issues collectively. These organizations demonstrate that local citizens are committed to working for justice in their community and nation. As one informant said, "I try to do a good job . . . if I'm not trying to do the best I can to improve water quality in my own personal environment, how am I going to provide that leadership to others?"

Discussion

The *Framework* acknowledged the contextual features of occupational performance by describing them as "overarching, underlying, embedded influence[s] on the process of service delivery" (AOTA, 2002, p. 614). This study demonstrates the vital connection between clean water in the physical environment and one's ability to engage in human occupations. Citizens of Letcher County were unable to carry out some of their daily occupations without making constant adjustments. Routines that typically become habits for most Americans were disrupted in their lives. New routines that were not necessary before the destruction of underground aquifers also had to be added to their daily occupations.

Residents of Letcher County also lost access to valued leisure occupations when local streams, lakes, and ponds became polluted. This created a profound sense of sadness and grief (Frances, 2006). They recognized that their rural county lacked access to museums, theaters, and other resources typical of urban environments. However, their expectation was that living in a rural area ought to provide the benefits of outdoor recreation in a safe, natural environment. Many felt forced to abandon valued outdoor leisure occupations altogether because of degradation in the physical environment.

The process of constantly adapting daily routines while adjusting or abandoning meaningful leisure occupations eventually became exhausting. One woman summed up the situation when she said, "I am sick and tired of water being the center of our lives." As Townsend and Wilcock (2003) argued, when people's daily occupations are regimented, confined, and exploited, it becomes a matter of justice. In Letcher County, international energy corporations engaging in contemporary coal-mining methods held economic and political power at state and national levels. At the same time, those living in the coalfields of Letcher County experienced occupational alienation, deprivation, and imbalance as a result of the privileged status afforded to their corporate neighbors who were free to ignore laws regulating the environment. Such systematic inequalities constituted a situation of occupational apartheid in which Letcher County residents were repeatedly exploited and marginalized.

In January 2003, a comprehensive report of the Headwaters Project was compiled by EKU faculty and was shared with their research partners in Letcher County. As of March 2005, the county judge–executive reported that data from the final report had been used to obtain $24 million in grant monies for water improvement projects. This use of the research results is in keeping with the PAR process in which data are used to address a specific problem. Although the county has made significant strides in addressing water quality in people's homes, many people still must rely on well water. In addition, the situation of occupational injustice remains throughout the county as residents continue to struggle with an increasing degradation of the natural environment and loss of leisure occupations.

Study Limitations

Although the snowball sampling technique is a well-known field research method, in this case it limited the participants to those who had telephones. Because Letcher County is listed by the Appalachian Regional Commission (2001) as persistently distressed with a 27% poverty rate, a significant number of households in the county have no telephones. The necessity of a telephone for arranging interviews meant that the poorest residents in the county were excluded from the sample. In addition, although African Americans are the primary minority ethnic group in the county, they represent only 0.5% of the population (U.S. Census Bureau, n.d.), and they are not represented in the sample.

Second, students were directed to people who might be willing to talk with them or those known to have concerns about their water. Thus, we have limited information from people who may think that there is no problem with the water. However, scheduled interviews could not always be conducted because of unforeseen events. In these instances, students frequently approached strangers and asked if they would be willing to be interviewed. Students usually found people willing to talk about their water.

Implications for Occupational Therapy

In the *Framework* (AOTA, 2002), occupational therapy practitioners are encouraged to consider organizations, populations, or entire communities as our clients. This study demonstrates that practitioners may act as consultants to help community members identify factors that lead to poor health and occupational injustice. Intervention to address occupational and social justice issues may include involvement in community groups and the media to increase public awareness; facilitation of group discussions in community agencies, health centers, or schools; and social action at rallies, health fairs, boycotts, workshops, and other social events (Wilcock, 1998, p. 227). Universities, community activists, other professionals, and community organizations that advocate for social justice can be resources for those who recognize that a community development approach is required for better health in a local population. ▲

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Heavy Metal Accumulation in Hot Water Tanks in a Region Experiencing Coal Waste Pollution and Comparison Between Regional Water Systems

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Abstract In 2000, a coal slurry impoundment failure in Martin County, Kentucky, caused concerns about contaminants entering municipal water supplies. Water samples taken from impacted and reference area hot water tanks often exceeded US EPA drinking water guidelines. Concentrations of As, Cd, Cr, Cu, Fe, Mn, and Pb had maxima of 119; 51.9; 154; 170,000; 976,000; 8,710; and 12,700 μg/L, respectively. Significantly different metal accumulation between counties indicated this procedure's utility for assessing long-term municipal water quality. Correlations between metal concentrations were strong and consistent for As, Ba, Cd, Cr, Co, and Fe indicating that some metals accumulate proportionally with others.

Keywords Coal slurry · Heavy metals · Drinking water · Correlations between metal concentrations

In 2000, a coal waste impoundment breach in Martin County, KY, USA released over 300 million gallons of coal sludge and black water into area creeks and eastern KY waterways. Local residents were unsatisfied with environmental impact assessments submitted by state agencies and private companies as they were conducted by research firms under subcontract with the responsible coal company (McSpirit et al. 2006).

In 2005, through efforts by area citizens and the KY State Environmental Quality Commission, an act was passed by the Kentucky General Assembly to release $150,000 of the natural resource damage settlement for an independent assessment of the long-term impacts of sludge spill on the public water system with citizen oversight (Kentucky Legislature 2005. Conference Budget Report HB 267. http://www.lrc.ky.gov/budget/05rs/50f.pdf).

Hot water tanks may indicate previous contamination from the water supply. Since sediment and precipitates accumulate in the tanks from the moment of installation, they may indicate what metals were distributed with the water supply. Stout and Papillo (Well water quality in the vicinity of a coal slurry impoundment near Williamson, West Virginia. Prepared in response to: Questions from citizens attending the 15 January 2004 training session of the Coal Impoundment Location and Warning System, Delbarton, WV. Wheeling Jesuit University, Wheeling, WV, USA) found that iron and lead were concentrated in a hot water heater 1,179 times and 11.75 times higher than the source well water, respectively. Arsenic was not detected in the source water, but concentrated to 150 μg/L in the hot water tank, 15 times greater than the US EPA drinking water standard (2003).

Uranium accumulated in hot water tanks from long-term, naturally occurring sources in well water in South Carolina, USA. Concentrations of this metal were lower in water passing through hot water tanks than in source water, indicating that the metal was being stored in the tanks. However, when the source water was remediated reducing uranium concentrations, levels in water passing

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through hot water tanks were higher than in the source water, indicating uranium remobilization (DeVol and Woodruff 2004).

The purpose of our research was to examine whether there had been any long-term human health exposures to heavy metal pollutants derived from coal slurry releases via the county public water supply. Hot water tanks were sampled as they were expected to integrate metal availability in source water over time. These tanks also were assessed as a means of comparing long-term water quality between public water systems.

Materials and Methods

Metals were selected for analysis based on their prevalence in coal slurry. They included mercury, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese and selenium (Booth et al. 1999; Goodarzi 2002; Huggins 2002; Wagner and Hlatshwayo 2005). Calcium also was analyzed because high calcium levels may accompany high levels of heavy metals (Stout, Ben. 4 January 2006. Email correspondence).

Members of Supporting Appalachia's Vital Environment (SAVE), a local environmental organization, helped recruit potential participants into our study. In addition to single-family homes, hot water tanks from stores, schools, government buildings, and other establishments were tested. Fifty-five samples were taken in Martin County during September and October 2005. Additional samples were collected from Somerset, Pulaski County, KY, USA ($n = 30$) in October 2005 and Berea, Madison County, KY, USA ($n = 33$) during December 2005. These were selected as reference locales based upon the ease of sampling, similarity in size of the three counties' water treatment plants, and a desire to represent typical communities in Eastern Kentucky. To assess whether the metal observed to accumulate in hot water tanks resulted from unusually high levels of metal in the source water, 16 additional samples were taken from the cold-water tap of some Martin County participants.

In Martin County, sample collection was conducted by teams consisting of one to three Eastern Kentucky University (EKU) personnel and one member of SAVE or another local resident to act as guide/community liaison. Participants were provided with an informational sheet describing the study and a request for a signature of consent. Information was collected about the hot water tank, regarding water usage, flushing of tank, age of home (or establishment), and years in residence. Global Positioning System (GPS) coordinates were also recorded. Full anonymity and confidentiality of households and other establishments was maintained for all data obtained.

New polyethylene (PE) bottles were used to collect samples directly from the drain valve of water heaters or cold water taps. After collection, sample bottles were placed in plastic, resealable bags and kept on ice until they were acidified using trace metal grade nitric acid (HNO_3; US EPA 2005). Chain of custody forms were maintained by all parties handling sample bottles. Most sample analysis was conducted by Severn Trent Laboratories (STL), St Louis, Missouri, USA, a National Environmental Laboratory Accreditation Program (NELAP) certified analytical laboratory using US EPA (2005) standard methods for inductively coupled plasma with mass spectrometry (ICP–MS) analysis for most metals (Method 6020) and cold vapor atomic absorption spectrometry (CVAAS) to measure mercury (Method 7470A). Some additional Hg samples were analyzed at the Environmental Research and Training Laboratory (ERTL) at the University of Kentucky using CVAAS methods developed by the American Public Health Association (APHA 2000). The 16 cold tap water samples were analyzed at the Ecotoxicology and Environmental Assessment Laboratory (EEAL), also at the University of Kentucky, using methods developed by the APHA (2000).

Basic descriptive statistics were calculated for each metal. These included: identification of median and maximum values, and calculation of the mean and standard error. Additionally, one-way analysis of variance (ANOVA) was run to detect differences between metal concentrations in the three counties. If a difference was detected, Scheffe's test was used to assess its significance. As some measurements for certain metals were below the reporting limit (BRL), a modification of US EPA methods were used in analysis (1996). For each metal, except Hg, ANOVAs and Scheffe's tests were conducted twice, once with BRLs set to half of the reporting limit (RL) and again with the BRLs set to zero. This was done to ensure that the significance of results was neither under, nor over estimated. The concentrations of each metal were regressed against the concentrations for every other metal to determine if any of them may accumulate together.

Results and Discussion

Results for median, maximum, and mean metal concentrations with standard error and percentage of samples from each county exceeding US EPA limits such as maximum contaminant levels (MCL), action levels (AL) or non-enforceable secondary water standards, are reported in Table 1 (US EPA 2003). Reporting limits varied from 0.2 μg/L for Hg to 6,250 μg/L for Ca (Table 2). No US EPA limits have been established for either Ca or Co. Barium, Hg and Se did not exceed US. EPA limits in

Table 1 Number of samples taken (n), median, mean, and maximum metal concentrations (µg/L) with standard error (SE) and percentage of samples over US EPA limits (OL) for each metal tested in each county

Metal	County	N	Median	Mean	Maximum	SE	OL
As 10 µg/L[a]	Martin	55	5.00	6.11	32.8	0.718	10%
	Pulaski	30	5.00	20.0	119	5.61	30%
	Madison	33	5.00	9.92	58.9	2.20	18%
Ba 2 mg/L[a]	Martin	55	89.2	137	909	19.6	0%
	Pulaski	30	50.7	105	731	25.9	0%
	Madison	33	33.0	123	649	32	0%
Ca none[b]	Martin	55	53,700	79,600	1,050,000	19,300	n/a
	Pulaski	30	26,500	42,700	197,000	8,160	n/a
	Madison	33	46,900	114,000	714,000	29,000	n/a
Cd 5 µg/L[a]	Martin	55	0.250	1.49	51.9	0.941	3%
	Pulaski	30	0.570	2.51	31.7	1.09	13%
	Madison	33	0.280	0.919	9.20	0.34	3%
Co none[b]	Martin	55	6.70	32.0	341	8.35	n/a
	Pulaski	30	4.65	33.5	354	13.7	n/a
	Madison	33	4.30	10.1	49.3	2.21	n/a
Cr 100 µg/L[a]	Martin	55	7.60	13.1	50.0	1.88	0%
	Pulaski	30	7.50	18.6	134	4.87	3%
	Madison	33	13.6	15.4	50.1	1.78	0%
Cu 1.3 mg/L[c]	Martin	55	307	4,600	116,000	2,300	16%
	Pulaski	30	4,530	27,700	141,000	34,100	77%
	Madison	33	1,170	16,800	170,000	7,220	42%
Fe 300 µg/L[d]	Martin	56	1,360	21,400	713,000	13,400	78%
	Pulaski	30	10,900	79,600	976,000	34,100	87%
	Madison	33	1,270	5,530	42,800	1,930	64%
Hg 2 µg/L[a]	Martin	52	0.00	0.007	0.370	0.007	0%
	Pulaski	11	0.00	0.080	0.430	0.041	0%
	Madison	33	0.00	0.003	0.065	0.000	0%
Mn 50 µg/L[d]	Martin	55	267	1,030	7,010	234	62%
	Pulaski	30	317	1,490	8,710	423	86%
	Madison	33	140	336	5,110	153	73%
Pb 15 µg/L[c]	Martin	55	27.7	123	1,910	46.2	77%
	Pulaski	30	320	1,610	12,700	582	86%
	Madison	33	42.4	337	2,240	102	70%
Se 50 µg/L[a]	Martin	54	2.50	2.09	2.50	0.086	0%
	Pulaski	30	2.50	2.42	3.30	0.071	0%
	Madison	33	2.50	1.88	2.50	0.131	0%

[a] US EPA Maximum Contaminant Level (MCL)

[b] No US EPA standards have been established for this element

[c] US EPA Action Level (AL)

[d] US EPA non-enforceable secondary drinking water standard

samples from any county. More than 60% of Fe, Mn, and Pb samples from all counties exceeded US EPA guidelines (Table 1). In fact, levels of Pb averaged 8.24, 22.5, and 108 times the U.S. EPA AL in Martin, Madison and Pulaski Counties, respectively. Copper and Ca also tended to accumulate at high levels. A few As and Cd samples from each county exceeded US EPA MCLs, and one Cr sample from Pulaski County exceeded the MCL.

Average concentrations of several metals varied significantly between counties (Table 2). ANOVA and Scheffe's test indicated that As, Ca, Fe, Mn, and Pb average values were significantly higher ($p \leq 0.05$) in Pulaski County than

Table 2 Comparison of average metal concentrations in hot water tanks from Madison (Mad), Martin (Mar), and Pulaski (Pul) counties using ANOVA and Scheffe's test

Metal	ANOVA		Scheffe's test	
	BRL = 1/2	BRL = 0	BRL = 1/2	BRL = 0
As	p = 0.002	p = 0.001	Pul > Mar	Pul > Mar
Ba	p = 0.668	p = 0.668	No difference	No difference
Ca	p = 0.097	p = 0.097	No difference	No difference
Cd	p = 0.539	p = 0.553	No difference	No difference
Cr	p = 0.382	p = 0.006	No difference	Pul > Mar
Co	p = 0.166	p = 0.168	No difference	No difference
Cu	p = 0.006	p = 0.006	Pul > Mar	Pul > Mar
Fe	p = 0.030	p = 0.030	Pul > Mar	Pul > Mar
Hg	Not done	p = 0.001	Not done	Pul > Mar and Mad
Mn	p = 0.031	p = 0.031	Pul > Mad	Pul > Mad
Pb	p < 0.001	p < 0.001	Pul > Mar and Mad	Pul > Mar and Mad
Se	p = 0.003	p = 0.966	No difference	Pul > Mad

All tests were done twice, once with below reporting limit (BRL) values set to zero and once with BRL values set to half the reporting limit

Reporting limit: As = 10 μg/L; Ba = 5.0–62.5 μg/L; Ca = 500–6,250 μg/L; Cd = 0.5 μg/L; Cr = 10–100 μg/L; Co, Mn, Se = 5.0–50 μg/L; Fe = 3.0–500 μg/L; Hg = 0.2–0.5 μg/L; Pb = 3.0–37.5 μg/L

Scheffe's test indicates significant differences in average metal concentration between counties at $p \leq 0.05$

Table 3 Correlations found between the accumulations of various metals from public water systems (n = 124)

Metal	County		
	Martin	Pulaski	Madison
As	**Ba**, *Co*, **Cu**, Pb	**Ba**, *Cr*, **Cu**	**Ba**, Cd, **Cu**, *Cr*, *Co*, Fe
Ba	**As**, **Ca**, **Cr**, Mn	**As**, **Ca**, **Cr**, Cu	**As**, Cd, **Ca**, **Cr**, Co, Fe
Cd	**Co**, Cu, **Fe**, *Pb*, Mn	**Co**, **Fe**, *Pb*, Se	As, Ba, Cr, **Co**, **Fe**
Ca	**Ba**, Mn	**Ba**	As, **Ba**, Cu
Cr	**Ba**, **Co**, Mn	*As*, **Ba**, **Co**, Cu	*As*, **Ba**, Cd, **Co**, Fe
Co	*As*, **Cd**, **Cr**, *Cu*, *Fe*, *Pb*, Mn	**Cd**, **Cr**, *Cu*, *Pb*	*As*, Ba, **Cd**, **Cr**, *Fe*
Cu	*As*, Cd, *Co*, Fe, Pb, *Mn*	*As*, Ba, Cr, *Co*	Ca, *Mn*
Fe	**Cd**, *Co*, Cu, *Pb*, *Mn*	**Cd**, *Pb*, *Mn*, Se	As, Ba, **Cd**, Cr, *Co*
Pb	As, *Cd*, *Co*, Cu, *Fe*, Mn	*Cd*, *Co*, *Fe*	–
Mn	Ba, Cd, Ca, Cr, Co, *Cu*, *Fe*, Pb	*Fe*	*Cu*
Se	-	Cd, Fe	–

Italics indicates that the metals indicated correlate in two counties, while bold indicates correlation in all three counties

Martin and/or Madison Counties when BRL values were set to zero and when set to half the RL. These tests also indicated that Cr, Hg, and Se average values were significantly higher ($p \leq 0.05$) in Pulaski County compared to Martin and/or Madison Counties when BRL values were set to zero.

Correlations between accumulated metal levels were especially strong and consistent for As, Ba, Cd, Cr, Co, and Fe (Table 3). In fact, these metals possessed significant Pearson correlation coefficients ($p < 0.05$) across all three county data sets. Similar relationships have been noted by others for various metals in groundwater (Bundschuh et al. 2004; Silliman et al. 2007). Given these correlations, if local communities or environmental groups use inexpensive, single indicator test kits to monitor ground water, they may infer the possible presence of a broad suite of elements from the occurrence of a few particular metals. This may allow them to decide where and when more expensive, definitive analytical testing should be conducted.

High concentrations of several metals of human health concern were measured in many hot water tanks. However, no clear relationship was observed between accumulation in the hot water tank and metal available in the source water, as sampled from the cold-water tap. Samples taken from 16 locations' cold water taps, the point in the home upon which US EPA MCLs were based, did not show any metal concentrations above their respective MCLs (US EPA 2003). These included several locations with high levels of As or Pb accumulation in the hot water tank. It seems that either hot water tanks are able to concentrate metals from source water very effectively [e.g., from levels below the MCL to levels well above the MCL as noted by Stout and Papillo (Well water quality in the vicinity of a coal slurry impoundment near Williamson, West Virginia. 2004)] or the source water formerly contained more metals. County water treatment plant annual reports do not indicate any high levels of metal contamination in the past.

Additionally, some of the accumulated Cu, Fe, and Pb could be derived from public water distribution system pipes or on-site plumbing rather than source water.

It is obvious that hot water tanks sometimes accumulated considerable quantities of heavy metals. In general, Pulaski County possessed a larger proportion of hot water tanks with higher quantities of metals. For 10 of the 12 metals analyzed, Pulaski County had the highest mean values, up to 8 of which were significantly (Table 2; Scheffe's test, $p < 0.05$) higher than Martin and/or Madison Counties, perhaps indicating that Pulaski County had lower quality source water than Martin County. Madison County may have possessed the best water quality source water as average values for 7 of 12 metals were higher in Martin County than Madison County. The only metal that was higher in Madison County than either Main or Pulaski Counties was Ca, the most benign metal studied. These results also indicate that sampling hot water tanks may provide a convenient way to compare the long-term quality of the water produced by different treatment plants. Assuming that sample groups are comparable, a water system that deposits fewer impurities into the hot water tanks of its customers has likely been producing higher quality water over a long period of time.

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Well water quality in the vicinity of a coal slurry impoundment near Williamson, West Virginia.

Prepared in response to:
Questions from citizens attending the January 15, 2004 training session of the Coal Impoundment Location and Warning System, Delbarton, West Virginia

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December 10, 2004

Executive summary

Fifteen wells were sampled within 2 air miles of the Sprouse Creek Slurry Impoundment at the request of citizens attending the January 15, 2004 training session of the Coal Slurry Impoundment Location and Warning System. Wells in the area of Sprigg, Merrimac, Rawl, and Lick Creek near Williamson, West Virginia, reportedly had good quality water approximately 10-15 years prior to this study. More recently, households consistently reported periodic "blackwater" events in their well water, fixtures that corroded within 2 years, red and black stains on their porcelain, walls, clothing and dishes, and health problems including cancer and kidney stones. This study focused on 7 heavy metals regulated by Environmental Protection Agency primary drinking water standards, and 5 metals regulated by secondary standards. An experimental design was implemented to capture spatial (geographic) and temporal (low flow versus high flow) variation in well water quality conditions. We hypothesized that if coal slurry was impacting wells, then well water would reflect the elemental constituents of coal slurry.

Primary drinking water standards for the 7 metals tested were exceeded 13 times in samples collected from 15 different wells. Standards were exceeded for lead (8), arsenic (2), barium (1), beryllium (1), and selenium (1), but not for cadmium or chromium. Lead was detected in 6 of 12 wells during low flow conditions with concentrations ranging from 6 to 23 ppb, and 5 of 12 wells exceeded the standard. Lead was detected in 7of 8 wells during high flow conditions with concentrations ranging from 9 to 110 ppb, and 3 wells exceeding the primary standard. Arsenic was detected in 1 of 12 wells sampled during low flow conditions, and no wells exceeded the primary water quality standard. Arsenic was detected in 6 of 8 wells during high flow conditions with concentrations ranging from 4.2 to 340.0 ppb and 2 wells exceeding the 10 ppb standard.

Secondary drinking water standards for the 5 metals tested were exceeded a total of 36 times in samples collected from 15 different wells. Standards were exceeded for iron (17), manganese (17), aluminum (1), and zinc (1), but not for copper. During low flow conditions 10 of 12 wells exceeded the 300 ppb secondary drinking water standard for iron. Iron exceeded the standard in all 8 wells sampled during high flow conditions, with

concentrations ranging from 371 to 57,588 ppb. Manganese concentrations during low flow conditions ranged from not detected in a spring and in a 26 foot deep dug well, to 2,999 ppb in a 76 foot deep drilled well (Table 1). Manganese exceeded the 50 ppb standard in 9 of 12 wells during low flow. Under high flow conditions manganese exceeded the secondary standard in all 8 wells sampled with concentrations ranging from 82 to 4,063 ppb.

One sample was collected by decanting water off the sludge from a hot water heater. The sludge was dark red, as was the liquid. The sample contained exceptionally high concentrations of 4 metals that exceeded primary standards including arsenic (150 ppb), barium (3,000 ppb), lead (188 ppb), and selenium (646 ppb). Most interesting, arsenic and selenium were not detected in the source well from which the hot water heater was supplied. For those elements detected in both the source well and the hot water heater, concentrations were 30 times greater for barium, 7 times greater for chromium, and 12 times greater for lead in the hot water heater versus the source well. Hot water heaters appear to represent a significant water supply concentrating mechanism for heavy metals regulated by primary standards. The dark red color of the sludge was due to 557,700 ppb of iron and 27,260 ppb of manganese.

A comparison of water quality during low flow (base flow) versus high flow (event flow) was conducted by re-sampling 5 wells in response to citizen concerns regarding "blackwater" in their wells following rainfall events. Arsenic was detected in 1 well during low flow, but in 4 of the 5 wells during high flow. Barium was detected consistently in all wells under all conditions. Beryllium and cadmium were not detected in the 5 wells under any flow condition. Chromium was detected in 3 wells during low flow and all 5 wells during high flow. Lead was detected in 3 wells during low flow and 4 wells during high flow. Selenium was detected in 1 well during low flow, but was not detected during high flow. Among the non-regulated chemicals tested, vanadium was detected in 3 of 5 wells during low flow, but was not detected during high flow. Flow condition causes significant differences in the elemental composition of well water in the study area.

A comparison of Williamson area well water with the available data from domestic wells in neighboring counties of southern West Virginia and Eastern Kentucky indicated that Williamson area wells had the poorest water quality in the coalfield region. Poor water quality in these communities had been indicated by some past studies, but refuted more recently in a study by the Agency for Toxic Substances and Disease Registry. The information presented here indicates significant metals contamination at concentrations well beyond what should be used as a water supply source. Additional studies are required to determine the exact source of contamination.

Based on the results of this study a thorough and comprehensive assessment of the relationship between well water quality and human health is warranted in the area of Sprigg, Merrimac, Rawl, and Lick Creek near Williamson, West Virginia.

Introduction

A study of drinking water quality was conducted in response to the requests of citizens at a meeting of the Coal Impoundment Study in Delbarton, West Virginia. Citizens were primarily concerned with potential health effects due to heavy metals in their well water, which they felt was related to the Sprouse Creek Slurry Impoundment (MSHA identification number: 1211-WV04-40516-02, WV DEP permit number: O-41-84) and an underground injection system. Prior to field sampling, a phone conversation with Dr. Diane Schafer, an orthopedic surgeon in Williamson, WV revealed her opinion that "there is no question about illnesses [in Mingo County] caused by poor water quality (personal communication, Feb.3, 2004)." She said that there are definitely some water quality problems and that Rawl is the worst of the communities. Among the citizens of Rawl, Sprigg, Merrimac, and Lick Creek, there are high incidences of Alzheimer's disease, blood problems, cancers not related to smoking, diseases of the environment, and Attention Deficit Disorder. According to Dr. Schafer, the water is "brackish." Illnesses that citizens have complained of also include: kidney stones and kidney failure, environmental toxic poisoning, arsenic poisoning, dementia, birth defects, cancer, thyroid problems, and gastrointestinal problems that appear to be related to *H. pylori* bacteria.

In response to their concerns, the investigators made arrangements with the Water Quality Laboratory at Heidelberg College to analyze 23 samples of water from wells used by citizens. The Water Quality Laboratory was chosen based on cost comparisons and because of their well-established well water sampling program including over 30,000 wells nationwide. Heavy metals were analyzed because this was of main concern to the citizens.

There are 2 categories that the metals standards fall into: regulated and non-regulated. Regulated metals are broken down into 3 categories: primary standards, secondary standards, and lifetime health advisories. The US Environmental Protection Agency (EPA) describes a National Primary Drinking Water Regulation (primary standard) as "a legally-enforceable standard that applies to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water" (EPA, 2004b). The National Secondary Drinking Water Regulation (secondary standard) is a "non-enforceable guideline regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. The EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards." This means that although the chemical may make the water smell, look, or taste peculiar, that does not necessarily mean it will harm your health (US EPA, 2004a). "Health Advisories are guidance values based on non-cancer health effects for different durations of exposure (e.g., one-day, ten-day, longer-term, and lifetime). Health Advisories provide technical guidance to EPA Regional Offices, State governments, and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination" (US EPA, 2004b).

Metals tested in this study and regulated by primary standards are: arsenic, barium, beryllium, cadmium, chromium, lead, and selenium. Metals regulated by secondary standards included: aluminum, copper, iron, manganese, and nickel. Metals regulated by lifetime advisories are sodium and zinc. Non-regulated chemicals tested in this study include calcium, strontium, cobalt, magnesium, potassium, silica, and vanadium. For non-regulated chemicals, health effects are either minimal or are not well known. It should also be known that standards referred to in this study are for the purpose of comparison because standards apply to public water systems, not private wells.

Hypothesis:

We hypothesized that if coal slurry was impacting wells, then well water would reflect the elemental constituents of coal slurry, particularly high levels of arsenic, barium, cadmium, chromium, lead, and selenium because these metals were observed in excess of primary standards in a coal slurry sample collected March 20,1985, approximately 4 miles south of Williamson (EPA, 1985). It was also noted that copper, iron, and manganese exceeded secondary standards in the coal slurry sample.

Materials and Methods

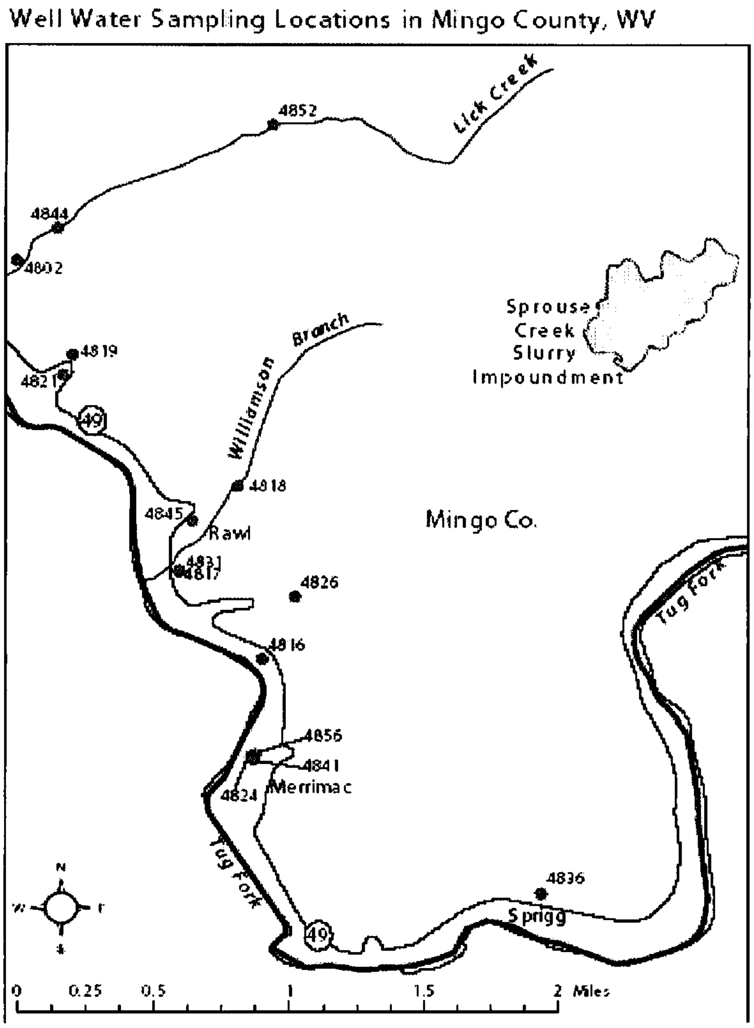
Sample collection and analysis

Water quality sampling followed the protocol for well water sampling as mandated by the Water Quality Laboratory at Heidelberg College. For each well, 3 plastic bottles were filled with water. One bottle was used for the analysis of arsenic, and the remaining 2 bottles were used for analysis of barium, beryllium, cadmium, chromium, lead, selenium, aluminum, copper, iron, manganese, nickel, sodium, zinc, calcium, strontium, cobalt, magnesium, potassium, silica, and vanadium. A "Cooperative Private Water Supply Testing Program Participant Information Sheet" was filled out for each well. A number was assigned to each well, and a bar code for each sample was placed on all 3 bottles and on the accompanying information sheet. Samples were analyzed in the Water Quality Laboratory using Standard Methods (Clesceri, *et al* 1999).

Water from wells 4819, 4844, 4802, and 4852 was taken from the kitchen tap. The cold water tap was allowed to run into the sink for approximately 1 minute. Each of the 3 bottles was filled in this stream of water and then labeled. The remaining well samples were taken directly from the well by first disconnecting the household system (typically located in the basement, crawlspace, or nearby shed) and then flushing for 1 minute before filling bottles as described above. Three samples were taken from sources that were not wells, including: a spring on the east side of the Norfolk Southern railroad tracks that is used as a water supply source by many area residents (4816), a municipal source originating from the Williamson water treatment plant and taken directly from the tap in a local business (4824), and a hot water heater (4831) from which supernatant water was decanted from the sludge that accumulated in the bottom of the heater. The sludge had been removed from the hot water heater and placed into a clean 5 gallon bucket prior to decanting. The well (4826) that feeds the hot water heater (4831) was also sampled after disconnecting it from the household system as described above.

Study area

Sampling locations were chosen geospatially to obtain representative wells in the 4 sub-watersheds of Lick Creek, Rawl, Merrimac, and Sprigg, WV. The investigators sampled at the head, middle, and bottom of the hollow in these watersheds (Map 1). Latitude and longitude were obtained using a global positioning system. Five wells were re-sampled during high flow conditions (described below) and thus have well numbers corresponding to previous sampling points. Three wells sampled during high water conditions were described by street addresses, but latitude and longitude were not acquired.

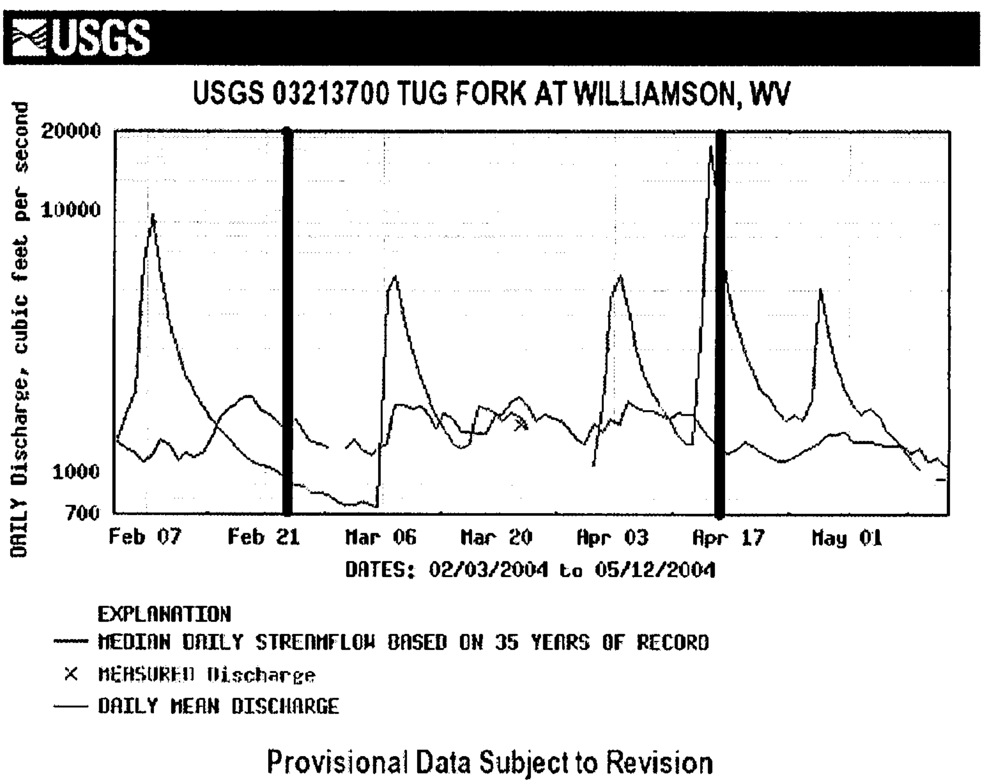


Map 1. Williamson area well water sampling locations, Mingo County, WV.

Sampling during low flow and high flow conditions

Fifteen samples were taken during a low flow period on February 25 and 26, 2004 when mean daily stream flow was between 882 and 841 cubic feet per second at the Tug Fork River gauging station at Williamson (Hydrograph 1). During low flow sampling discharge in the Tug Fork River was approximately 38% of the 35 year median flow condition for those dates.

Eight samples were taken during a high flow period on April 16, 2004 when mean daily stream flow was 5,120 cubic feet per second in the Tug Fork River, or 270% the 35 year median flow condition for that date (Hydrograph 1). The 8 high flow samples were collected by citizens who had been trained by the investigators on how to take samples, label them, fill out data sheets, and mail them according to the Water Quality Lab protocol. The samples were labeled and mailed to Wheeling Jesuit University where sample data sheets were photocopied prior to mailing the samples to the Water Quality Laboratory.



Hydrograph 1. Stream discharge (ft^3/second) at the US Geological Survey Tug Fork recording station near Williamson, West Virginia showing discharge in relation to median flow on February 25-26, and April 16, 2004 well water sampling dates (indicated by vertical black lines).

Results

Water chemistry in Williamson area wells

Well water was tested for 7 metals regulated by primary standards, 5 metals regulated by secondary standards, 2 metals regulated by lifetime health advisories, and 7 non-regulated chemicals.

Metals regulated by primary standards in Williamson area well water

Six of 7 metals that were tested for and that are regulated by primary standards were detected in at least one Williamson area well (Tables 1 & 2). Cadmium was not detected in any well sample. Arsenic was detected in 6 of the 15 different wells, twice in excess the primary standard. Barium was detected in 12 of the 15 wells, once in excess of the standard. Beryllium was detected in 2 of the 15 wells, once in excess of the standard. Chromium was detected in 11 of 15 wells and did not exceed the standard. Lead was detected in 14 of the 15 wells, exceeding the standard in 7 different wells including twice in 1 of the 5 wells that was re-sampled during high flow conditions. Selenium was detected in 1 well and that sample exceeded the primary standard. Primary drinking water standards for the 7 metals tested were exceeded 13 times in samples collected from 15 different wells. Standards were exceeded for lead (8), arsenic (2), barium (1), beryllium (1), and selenium (1), but not for cadmium or chromium.

A sample from a spring used by many families as their drinking water source yielded 1 chemical, chromium, regulated by primary standards. The spring sample had 7 ppb chromium, and was well below the standard of 10 ppb. A sample from the Williamson area municipal supply yielded 2 metals, chromium (3 ppb) and lead (16 ppb) that were tested for and are regulated by primary drinking water standards. In the municipal sample only lead exceeded the 15 ppb standard. In contrast, a sample of the supernatant water decanted from sludge that had collected in the bottom of a hot water heater (source identity 4831) yielded 6 of the 7 tested metals of primary concern, with only cadmium not detected. Four of the 7 metals tested in the hot water heater exceeded primary drinking water standards by factors of 15X for arsenic (150 ppb), 1.5X for barium (3,000 ppb), 12.5X for lead (188 ppb), and 129.2X for selenium (646 ppb). Most interesting, arsenic and selenium were not detected in the sample from the source well (4826) from which the hot water heater (4831) was supplied. Of the 7 metals tested only lead exceeded the primary standard in the source well. When concentration factors for metals of primary concern are calculated by dividing the concentration in the hot water heater by the concentration in the source well (for those elements detected in the source well) the multiplication factor for barium is 30X, chromium 7.3X, and lead 11.8X.

Whereas no households with drilled wells had used their well water as a drinking source for some time, all households actively used their well water as a source for bathing and washing. Therefore, concentration of metals in hot water heaters followed by vaporization during bathing (most used showers) indicates that inhalation, ingestion, and absorption may be significant human exposure pathways. Many households complained of difficulty in keeping the walls of their bathrooms clean due to buildup of black and red precipitates. Additionally, all households had to use plastic, not metal, fixtures in their bathrooms and kitchen sinks because metal fixtures corroded and dissolved "within 2 years." Most households had replaced their hot water heater within the past 2 years because of corrosion leading to failure of their hot water heater. One additional observation was that when well samples were collected by disengaging the well supply from the household plumbing, as was done in 10 of the 15 different wells sampled (5 samples were collected from the tap as stated and identified specifically in the Methods Section), derelict hot water heaters were observed alongside new hot water heaters in most of the basements and sheds that were visited.

Arsenic was detected in 1 of 12 wells sampled during low flow conditions, with a concentration of 3.2 ppb being below the 10 ppb primary water quality standard (Table 1). Arsenic was 150 ppb in the sample collected from the hot water heater. Arsenic was detected in 6 of 8 wells during high flow conditions with concentrations ranging from 4.2 to 340.0 ppb where detected, and 2 wells exceeding the 10 ppb standard (Table 2).

Barium was detected in 10 of 12 wells sampled at base flow, and one well yielding 2,400 ppb exceeded the 2,000 ppb standard (Table 1). Barium was not detected in the spring or the municipal supply. Barium was 3,000 ppb in the sample from the hot water heater. Barium was detected in 7 of 8 wells tested during high flow conditions with concentrations ranging from 200 to 500 ppb (Table 2).

Beryllium was not detected in wells at low flow, the municipal water sample, or the sample from the spring (Table 1). Beryllium was detected at 1 ppb in the hot water heater sample. Under high flow conditions beryllium was detected in 2 of 8 wells with concentrations of 1 and 7 ppb, therefore one sample exceeded the standard of 4 ppb at high flow (Table 2).

Cadmium was the only metal out of 7 metals tested that are regulated by primary drinking water standards that was not detected in any samples under any condition in Williamson area wells (Tables 1 & 2). Cadmium was also the only metal regulated by primary drinking water standards that was not detected in the sample from the hot water heater.

Chromium was detected in 6 of 12 wells under low flow conditions, with concentrations of 3 to 9 ppb being well below the standard of 100 ppb (Table 1). Chromium was detected in the spring (7 ppb), the municipal water sample (3 ppb), and the hot water heater (29 ppb). Under high flow conditions chromium was detected in all 8 wells with concentrations ranging from 2 to 24 ppb (Table 2). Chromium did not exceed primary drinking water standard of 100 ppb in any of the wells tested.

Lead was detected in 6 of 12 wells during low flow conditions with concentrations ranging from 6 to 23 ppb (Table 1). Five of 12 wells exceeded the 15 ppb primary standard. Lead was not detected in the spring, but exceeded the primary standard in the municipal water sample (16 ppb) and was 188 ppb in the hot water heater sample.

Lead was detected in 7 of 8 wells under high flow conditions with concentrations ranging from 9 to 110 ppb, and 3 wells exceeded the primary standard (Table 2).

Selenium was detected in only 1 of 12 wells under low flow conditions with a concentration of 65 ppb in excess of the 50 ppb standard (Table 1). Selenium was not detected in the spring or the municipal water sample. The selenium concentration was 646 ppb in the sample from the hot water heater. Selenium was not detected in any well under high flow conditions (Table 2).

Metals regulated by secondary standards in Williamson area well water

All 5 of the metals tested that are regulated by secondary drinking water standards were detected in Williamson area wells (Tables 1 & 2). Aluminum was detected in 12 of the 15 different wells tested, and the aluminum secondary standard was exceeded in 1 well. Copper was detected in 3 of 15 different wells and did not exceed the secondary standard in any well. Iron was detected in all 15 wells and exceeded the secondary standard in 13 of the wells, including twice in 4 of the 5 wells that were re-sampled during high flow conditions. Manganese was detected in 14 of the 15 different wells tested. Manganese exceeded the secondary standard in 13 of the 15 wells, including twice in 4 of the 5 wells re-sampled during high flow conditions. Zinc was detected in 14 of the 15 different wells tested. Zinc exceeded the secondary drinking water standard in 1 of the 15 wells. Secondary drinking water standards for the 5 metals tested were exceeded a total of 36 times in samples collected from 15 different wells. Standards were exceeded for iron (17), manganese (17), aluminum (1), and zinc (1), but not for copper.

A spring water sample contained only 1 of 5 metals tested and regulated by secondary standards: iron at 14 ppb. The sample from the Williamson municipal supply contained aluminum at 30 ppb and manganese at 35 ppb. In contrast, a sample of supernatant water decanted from the sludge which had collected in the bottom of a hot water heater (source identity 4831) yielded all 5 of the tested metals of secondary concern. Two of the 5 metals tested in the hot water heater exceeded secondary drinking water standards by factors of 1,859X for iron, and 5,452X for manganese. Most interesting, iron was 1.6X above standard and manganese 1.1X above standard in the sample from the source well (4826) from which the hot water heater (4831) was supplied. Here again, the hot water heater acts as a concentrating mechanism from which vaporization and subsequent inhalation, as well as ingestion and absorption exposure during bathing may be a significant human exposure pathway as described previously for metals of primary concern. Neither copper nor aluminum were detected in the source well, but both were detected in the hot water heater. Zinc was concentrated by a factor of 81.5X in the hot water heater (4831) compared to the source well (4826), iron was concentrated by 1,179.1X, and manganese 485.6X.

Aluminum was detected in 8 of 12 wells tested during base flow condition with concentrations ranging from 10 to 60 ppb (Table 1). Aluminum was not detected in the spring and was 30 ppb in the municipal water sample. Aluminum was 200 ppb in the hot water heater sample, equal to the 200 ppb secondary standard. Aluminum concentrations ranged from 30 to 170 ppb during high flow with one exception: one well tested during high flow had a concentration of 8,030 ppb, well in excess of the 200 ppb secondary standard (Table 2).

Copper was detected in only 1 well at base flow with a concentration of 53 ppb, well below the 1,300 ppb secondary standard (Table 1). Copper was not detected in the spring or the municipal supply and was below the standard with a concentration of 390 ppb in the hot water heater. Copper was detected in 2 of 8 wells sampled during high flow conditions with concentrations of 131 and 758 ppb being below the secondary standard (Table 2).

Iron was the predominant metal regulated by secondary standards that was detected in study wells, with concentrations ranging from 39 ppb to 25,280 ppb (Table 1). Iron was not detected in the sample from the municipal water supply, and 14 ppb were found in the spring water sample. Ten of 12 wells exceeded the drinking water standard of 300ppb during base flow. Iron was 557,700 ppb in the sample from the hot water heater. Iron exceeded the 300 ppb standard in all wells under high flow conditions, with concentrations ranging from 371 to 57,588 ppb (Table 2).

Manganese concentrations under low flow conditions ranged from not detected in the spring and a 26 foot deep dug well to 2,999 ppb in a 76-foot-deep drilled well (Table 1). Manganese was 35 ppb in the municipal water sample. Manganese exceeded the 50 ppb standard in 9 of 12 wells. Manganese was 27,260 ppb in the sample from the hot water heater. Under high flow conditions manganese exceeded the secondary standard in all 8 wells sampled with concentrations ranging from 82 to 4,063 ppb (Table 2).

Zinc was detected in 9 of 12 wells sampled during low flow conditions with concentrations ranging from 12 to 239 ppb, and no samples in excess of the 5,000 ppb secondary standard (Table 1). Zinc was not detected in the spring or the municipal supply. The hot water heater had a zinc concentration of 2,118 ppb. Zinc was detected in all 8 wells tested during high flow conditions and one well exceeded the secondary standard with a concentration of 5,658 ppb (Table 2).

<u>Regulated chemicals with lifetime health advisories in Williamson area well water</u>

Two metals tested and regulated by lifetime health advisories included nickel and sodium. Nickel was detected in only one for the 15 wells tested; a concentration of 285 ppb in excess of the 10 ppb standard (Tables 1 & 2). Nickel was not detected in the spring, the municipal supply, or the hot water heater (Table 1). Nickel was detected in only one well, and that sample was collected during high flow conditions (Table 2).

Sodium was detected in all samples ranging in concentration from 7,600 to 184,400 ppb during low flow conditions (Table 1), and 8,300 to 189,100 ppb during high flow conditions (Table 2). In wells sodium exceeded the 20,000 ppb standard in 13 of the 15 different wells tested (Tables 1 & 2). The sodium standard was exceeded in 10 of 12 wells tested during low flow (Table 1), and 6 of 8 wells tested during high flow, including twice in 4 of the 5 wells re-tested during high flow (Table 2). In total, sodium standards were exceeded 16 times (Tables 1 & 2). Sodium was 2.1X the standard in the sample from the spring, and 2.1X the standard in the sample from the municipal water supply (Table 1). Interestingly, sodium was only 1.6X the sodium standard in the hot water heater, and had a concentration factor of only 3.3X compared to the source well (source identity 4826) from which the hot water heater (source identity 4831) was supplied. Therefore, sodium had the lowest concentration factor of any of the regulated chemicals that were detected in the source well.

Non-regulated chemicals in Williamson area well water

Calcium, magnesium, potassium, and silica were present in all wells, springs, the municipal water sample, and the hot water heater tested under both low and high flow conditions (Tables 1 & 2). Calcium and magnesium were the most abundant non-regulated chemicals tested. Potassium and silica were also present in high concentrations relative to other elements.

Strontium was present in 8 of 12 wells tested during low flow conditions (Table 1), and 4 of 8 wells tested under high flow conditions (Table 2). Cobalt was detected in one well during low flow conditions (Table 1), and one well tested during high flow conditions (Table 2). Vanadium was detected in 5 wells tested during low flow conditions, in the municipal water sample, and in the hot water heater sample (Table 1). Vanadium was not detected in any of the 8 wells tested during high flow conditions (Table 2).

Of the 7 non-regulated chemicals tested, strontium and vanadium were not detected in the source well (4826) but were detected in the hot water heater (4831). Multiplication factors from source to hot water heater for the other 5 non-regulated chemicals indicated the following rates of increase: calcium=1.9X, magnesium=1.1X, potassium=1X, and silica=13.2X. Cobalt was not detected in either the source or the hot water heater. Of the non-regulated chemicals, only silica multiplied to the extent witnessed for many of the regulated chemicals.

Table 1. Summary of well water chemistry (*u* g/l) during low flow conditions within 3 miles of a coal slurry impoundment in Mingo County, WV, February 25 & 26, 2004 (n.d.=non-detect, values shown in bold with borders exceed EPA limits).

Source information (12 househhold wells, a spring used by many households, the municipal water supply, and a hot water heater)

source	spring	well	well	well	well	muncpl.	well	well	well	well	well	well	well	well	heater
well depth (feet)	0	26	158	55	220		100	85	100	79	150	78	189	100	100
location in hollow	bottom	middle	head	head	middle	tap	bottom	bottom	bottom	head	bottom	bottom	middle	bottom	bottom
source water hardness	207	130	89	70	120	240	158	207	229	90	403	185	301	240	151
source identity (Map 1).	4816	4821	4818	4852	4819	4824	4802	4856	4817	4826	4844	4836	4845	4841	4831

Regulated Chemicals (all values in *u* g/l, micrograms per liter, or parts per billion)

	EPA stndrd.	spring	well	well	well	well	muncpl	well	well	well	well	well	well	well	well	heater
		Primary (enforceable) standards														
Arsenic	**10**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3	n.d.	**150**
Barium	**2000**	n.d.	n.d.	700	500	400	n.d.	200	900	300	100	n.d.	100	100	**2400**	**3000**
Beryllium	**4**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1
Cadmium	**5**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Chromium	**100**	7	n.d.	n.d.	n.d.	n.d.	3	6	3	n.d.	4	7	9	7	n.d.	29
Lead	**15**	n.d.	n.d.	n.d.	n.d.	n.d.	**16**	6	n.d.	n.d.	**16**	**19**	**20**	**23**	**16**	**188**
Selenium	**50**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	**65**	n.d.	n.d.	**646**
		Secondary (recommended) standards														
Aluminum	**200**	n.d.	10	60	n.d.	50	30	60	50	60	n.d.	n.d.	60	50	n.d.	200
Copper	**1300**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	53	n.d.	n.d.	n.d.	n.d.	n.d.	390
Iron	**300**	14	271	120	**364**	39	n.d.	**1257**	**5339**	**10553**	**473**	**1015**	**1569**	**25280**	**1221**	**557700**
Manganese	**50**	n.d.	n.d.	23	29	**52**	35	**67**	**269**	**308**	**55**	**57**	**2999**	**435**	**157**	**27260**
Zinc	**5000**	n.d.	64	n.d.	25	n.d.	n.d.	137	15	49	26	48	239	67	61	2118
		Lifetime health advisory														
Nickel	**100**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sodium	**20000**	**41300**	**25500**	**83700**	**23900**	**106700**	**42300**	**26300**	**29300**	**30400**	9500	**101000**	7600	**41100**	**184400**	**31200**
		Summary statisitics														
exceedence of standards		1	1	1	2	2	2	3	3	3	3	4	4	4	5	7
best-to-worst ranking		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Non-regulated (N.R.) chemicals

Calcium	**N.R.**	42000	25000	22400	17100	31500	48400	36900	53500	58000	24200	85000	52600	70700	65500	46700
Strontium	**N.R.**	1500	n.d.	930	n.d.	720	700	650	840	760	n.d.	2210	n.d.	660	2580	1210
Cobalt	**N.R.**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	12	n.d.	n.d.	n.d.	n.d.
Magnesium	**N.R.**	24800	16400	8100	6600	10000	28800	15900	17800	20500	7200	46400	13000	30100	18500	8200
Potassium	**N.R.**	7600	4100	3400	3400	3500	3400	3300	3900	3500	4300	8900	4000	3700	4200	4200
Silica	**N.R.**	3940	5120	7040	8000	7820	3150	7800	12020	10600	7480	4240	11150	9050	10520	98590
Vanadium	**N.R.**	n.d.	10	n.d.	35	n.d.	10	n.d.	n.d.	13	n.d.	n.d.	16	22	n.d.	91

Table 2. Summary of well water chemistry (*u* g/l) during high flow conditions within 3 miles of a coal slurry impoundment in Mingo County, WV, April 16, 2004 (n.d.=non-detect, values shown in bold with borders exceed EPA limit

source	well	well	well	well	well	well	well	well
well depth (feet)	78	85	100	189	55	220	120	n/a
location in hollow	bottom	bottom	bottom	middle	head	middle	middle	n/a
source water hardness	163.6	90.2	136.4	246.9	68.1	72	186	757.9
source identity (Map 1).	4836	n/a	4802	4845	4852	4819	n/a	n/a

Regulated Chemicals (all values in *u* g/l, micrograms per liter, or parts per billion)

	EPA standard	well	well	well	well	well	well	well	well
		Primary (enforceable) standards							
Arsenic	**10**	n.d.	8	4	8	**44**	**340**	5	n.d.
Barium	**2000**	200	500	200	400	500	500	400	n.d
Beryllium	**4**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1	**7**
Cadmium	**5**	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d	n.d
Chromium	**100**	6	17	4	8	2	4	18	24
Lead	**15**	10	12	10	**22**	9	n.d.	**110**	**30**
Selenium	**50**	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d	n.d
		Secondary (recommended) standards							
Aluminum	**200**	170	70	70	70	30	40	50	**8030**
Copper	**1300**	n.d.	n.d.	n.d.	131	n.d.	n.d.	758	n.d.
Iron	**300**	**7586**	**57588**	**2203**	**27327**	**4214**	**9701**	**25059**	**371**
Manganese	**50**	**2890**	**511**	**171**	**387**	**82**	**452**	**2953**	**4063**
Zinc	**5000**	1000	419	74	388	62	70	**5658**	712
		Lifetime health advisory							
Nickel	**100**	n.d	n.d	n.d	n.d	n.d.	n.d.	n.d	**285**
Sodium	**20000**	8300	15700	**35300**	**43200**	**30900**	**189100**	**61500**	**55800**
		Summary statisitics							
exceedence of standards		2	2	3	4	4	4	5	7
best-to-worst ranking		1	2	3	4	5	6	7	8

Non-regulated (N.R.) chemicals

Calcium	**N.R.**	47300	20700	33100	60800	17300	19000	48600	99500
Strontium	**N.R.**	n.d.	n.d	640	680	510	600	n.d	n.d
Cobalt	**N.R.**	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d	179
Magnesium	**N.R.**	11100	9400	13000	23100	6000	6000	15700	123700
Potassium	**N.R.**	2200	2400	2300	2300	2400	3800	2300	18300
Silica	**N.R.**	9720	11910	7050	9670	6510	5710	9440	13560
Vanadium	**N.R.**	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d	n.d

A comparison of 5 wells tested during low flow versus high flow conditions

Five wells sampled during low flow conditions were re-sampled during high flow conditions (Table 3). The comparison included wells that ranged from 55-220 feet in depth and included sites in the head, middle, and bottom of the hollows. The comparison also included some of the better wells in terms of water quality (4852, 4819, and 4802) and some of the worst (4836 and 4845). The compared wells had consistently lower hardness during high flow events than during low flow; an apparent dilution effect. Lower hardness was the result of reduced calcium and magnesium concentrations. Iron and manganese, however, were typically greater during high flow and consistently exceeded water quality standards.

Regulated chemicals were detected 2.25X more frequently during high versus low flow events in 4 of the 5 wells compared. In the other well the detection of regulated chemicals decreased by 1, specifically selenium. The number of metals in excess of water quality standards declined by 2 in well 4836, stayed the same in 2 wells, and increased by 2 in the 2 other wells that were re-sampled. Many of the chemical concentrations measured at low flow were similar at high flow. For instance, wells with relatively low hardness at low flow also had low hardness at high flow compared to other wells. Likewise, high hardness wells had relatively high hardness under high or low flow conditions.

However, the composition of some specific elements in well water changed considerably due to flow conditions. For instance, vanadium was detected in 3 of 5 wells during low flow, but was not detected during high flow. The reverse was also apparent, for instance, with arsenic detected in only one of the 5 re-sampled wells at low flow, but 4 of 5 wells during high flow. Copper was detected only once in wells, during high flow. Selenium was detected only once in wells, during low flow.

Arsenic was not detected in well 4836 under any flow condition. Arsenic was detected in well 4845 under both flow conditions. In 3 other wells arsenic was detected only during the high flow event. In 2 of those wells, arsenic exceeded the 10 ppb standard with values of 44 and 340 ppb. Arsenic at 340 ppb was the highest level observed during this study.

Chromium was detected in 3 wells at both high and low flow, but 2 other wells only at high flow. High flow conditions resulted in lead being detected in one well where it had not previously been detected. Otherwise, chromium was consistently detected in (3 wells) or not detected (one well), regardless of flow conditions. Selenium had been detected in well 4836 during low flow, but was not detected in that well or any other well during high flow.

Table 3. Comparison of well water chemistry (*u* g/l) during low flow (base flow, February 25 & 26, 2004) versus high flow (blackwater, April 16, 2004) conditions (n.d.=non-detect, values shown in bold with borders exceed EPA limits).

source identity (Map 1).	well 4819		well 4852		well 4836		well 4845		well 4802	
well depth (feet)	220		55		78		189		100	
location in hollow	middle		head		bottom		middle		bottom	
source water hardness	120	72	70	68	185	164	301	247	158	136
flow condition	low	high	low	high	low	high	low	high	low	high

Regulated Chemicals (all values in *u* g/l, micrograms per liter, or parts per billion)

	EPA standard	low	high	low	high	low	high	low	high	low	high
Primary (enforceable) standards											
Arsenic	**10**	n.d.	**340**	n.d.	**44**	n.d.	n.d.	3	8	n.d.	4
Barium	**2000**	400	500	500	500	100	200	100	400	200	200
Beryllium	**4**	n.d.	n.d.	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cadmium	**5**	n.d.	n.d.	n.d.	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Chromium	**100**	n.d.	4	n.d.	2	9	6	7	8	6	4
Lead	**15**	n.d.	n.d.	n.d.	9	**20**	10	**23**	**22**	6	10
Selenium	**50**	n.d.	n.d.	n.d.	n.d.	**65**	n.d.	n.d.	n.d.	n.d.	n.d.
Secondary (recommended) standards											
Aluminum	**200**	50	40	n.d.	30	60	170	50	70	60	70
Copper	**1300**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	131	n.d.	n.d.
Iron	**300**	39	**9704**	**364**	**4214**	**1569**	**7586**	**25280**	**27327**	**1257**	**2203**
Manganese	**50**	**52**	**452**	29	**82**	**2999**	**2890**	**435**	**387**	**67**	**171**
Zinc	**5000**	n.d.	70	25	62	239	1000	67	388	137	74
Lifetime health advisory											
Nickel	**100**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d	n.d.	n.d	n.d.	n.d
Sodium	**20000**	**106700**	**189100**	**23900**	**30900**	7600	8300	**41100**	**43200**	**26300**	**35300**
Summary statisitics											
exceedence of standards		2	4	2	4	4	2	4	4	3	3
number of detects		5	8	5	9	9	8	9	10	8	9

Non-regulated (N.R.) chemicals

		low	high	low	high	low	high	low	high	low	high
Calcium	**N.R.**	31500	19000	17100	17300	52600	47300	70700	60800	36900	33100
Strontium	**N.R.**	720	600	n.d.	510	n.d.	n.d.	660	680	650	640
Cobalt	**N.R.**	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Magnesium	**N.R.**	10000	6000	6600	6000	13000	11100	30100	23100	15900	13000
Potassium	**N.R.**	3500	3800	3400	2400	4000	2200	3700	2300	3300	2300
Silica	**N.R.**	7820	5710	8000	6510	11150	9720	9050	9670	7800	7050
Vanadium	**N.R.**	n.d.	n.d.	35	n.d.	16	n.d.	22	n.d.	n.d.	n.d.

A comparison of Williamson wells with regional domestic water wells

The results of well water sampling in the Williamson area were compared to results available from nearby domestic well water samples from southern West Virginia and Eastern Kentucky (Figures 1-5, Table 4). Two metals of greatest concern include arsenic (Figure 1) and lead (Figure 2). 2 additional metals that are of secondary concern, iron (Figure 2) and manganese (Figure 3) were also plotted because they are important indicators of coal related contamination. Sodium was also compared because it often exceeded lifetime health advisories in Williamson area wells (Figure 5). Summary statistics including sample size, percent of wells where elements were detected, and percent of samples collected that exceeded standards are shown in Table 4.

Samples for comparison in West Virginia counties were collected in 1997-1999 by the Division of Water Resources Groundwater Program and can be found in Appendix B of the Department of Environmental Protection's Biennial Report to the Legislature (WV DEP, 2002). Sample data for comparison in Kentucky counties were downloaded from the Kentucky Groundwater Data Repository (Kentucky Geological Survey, 2003). For Kentucky counties samples were selected for wells sampled 1) from 1994-2003, 2) in domestic water use designation wells only, and 3) by Kentucky Division of Water Resources or the Natural Resources Environmental Protection Council.

Arsenic concentrations in Williamson wells exceeded the primary drinking water standard in 2 of 8 wells (25%) during high flow conditions (Figure 1, Table 4). The 340 ppb in one well was the highest arsenic concentration in any of the regional wells. The next highest arsenic value was a Williamson well under high flow conditions at 44 ppb. Arsenic was detected in 75% of the Williamson wells during high flow conditions, and 8% of Williamson wells under low flow. Arsenic was not detected in any of the 12 wells sampled by WV DEP in Wyoming, McDowell, and Mingo Counties, West Virginia. Arsenic was detected in 14 of the 79 wells tested in Kentucky counties, including 13% of Pike County wells and 22% of Martin county wells. The highest concentration in Pike County wells was <2 ppb. Four Martin County wells exceeded the primary standard with values of 11-14ppb. Arsenic was not detected in any of the 11 Floyd County wells, however, we did locate a pollution monitoring well in Floyd County with an arsenic level of 172 ppb (data not included), approximately one-half the level witnessed in the exceptionally high arsenic concentration in one Williamson well.

Lead is abundant in Williamson area wells compared to other domestic wells (Figure 2, Table 4). One sample contained 110 ppb lead, the highest lead concentration in regional samples, and from a different well than the one that had the extraordinarily high concentration of arsenic. Lead was detected in 50% of low flow and 88% of high flow samples in the Williamson area. Lead was not detected in the 12 samples from the DEP Water Resources groundwater study. Lead was detected in 28% of Pike County samples, 18% of Martin County samples, and 45% of samples from Floyd County.

Lead exceeded the standard in 42% of Williamson low flow samples and 38% of Williamson high flow samples. Lead exceeded drinking water standards in 4% of Pike County, 4% of Martin County, and 9% of Floyd County domestic well water samples. Average lead concentrations in Williamson area samples greatly exceed average lead concentrations in other regional wells.

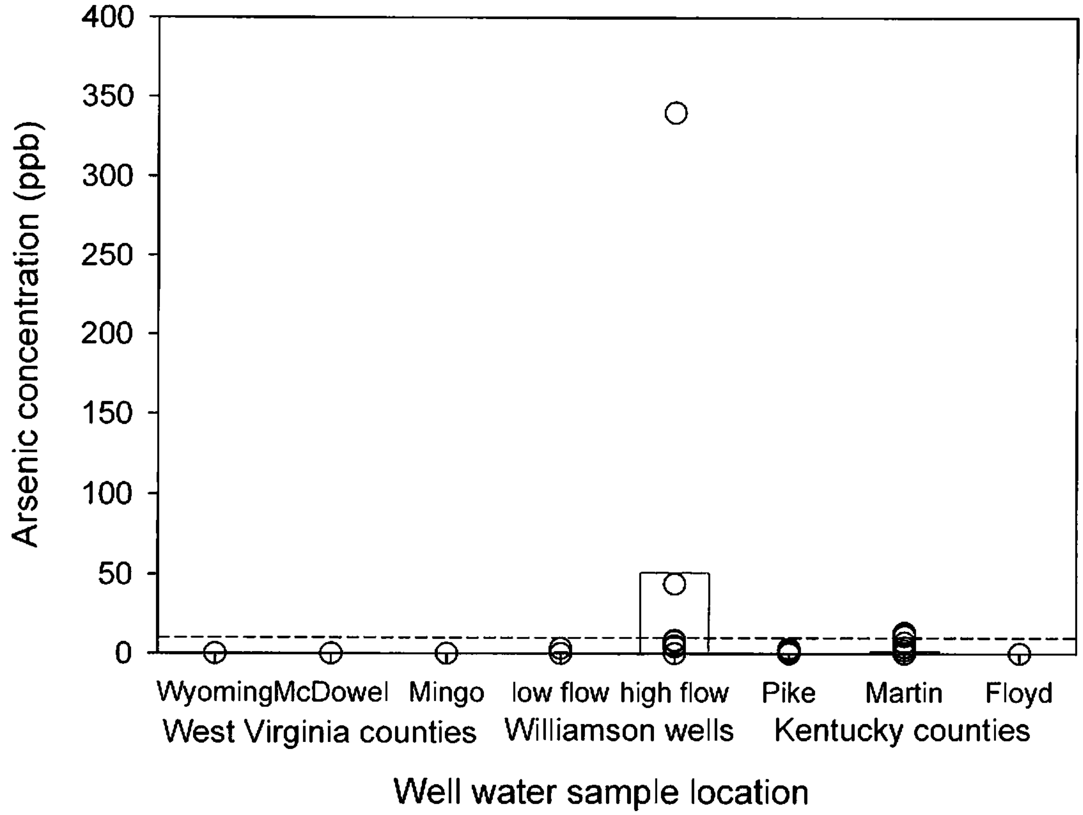
Iron (Figure 3) and manganese (Figure 4) concentrations followed patterns similar to those of arsenic and lead when comparing regional wells. Both peak and average concentrations of these elements were greater in Williamson area wells during high flow than in any other wells. During low flow, average iron concentrations in Williamson area wells were marginally less than in Pike County wells, as were peak iron concentrations. Average manganese concentrations in Williamson area wells during low flow were similar to those of Pike County and McDowell County. Both iron and manganese were detected in the vast majority of the wells in the region (Table 4).

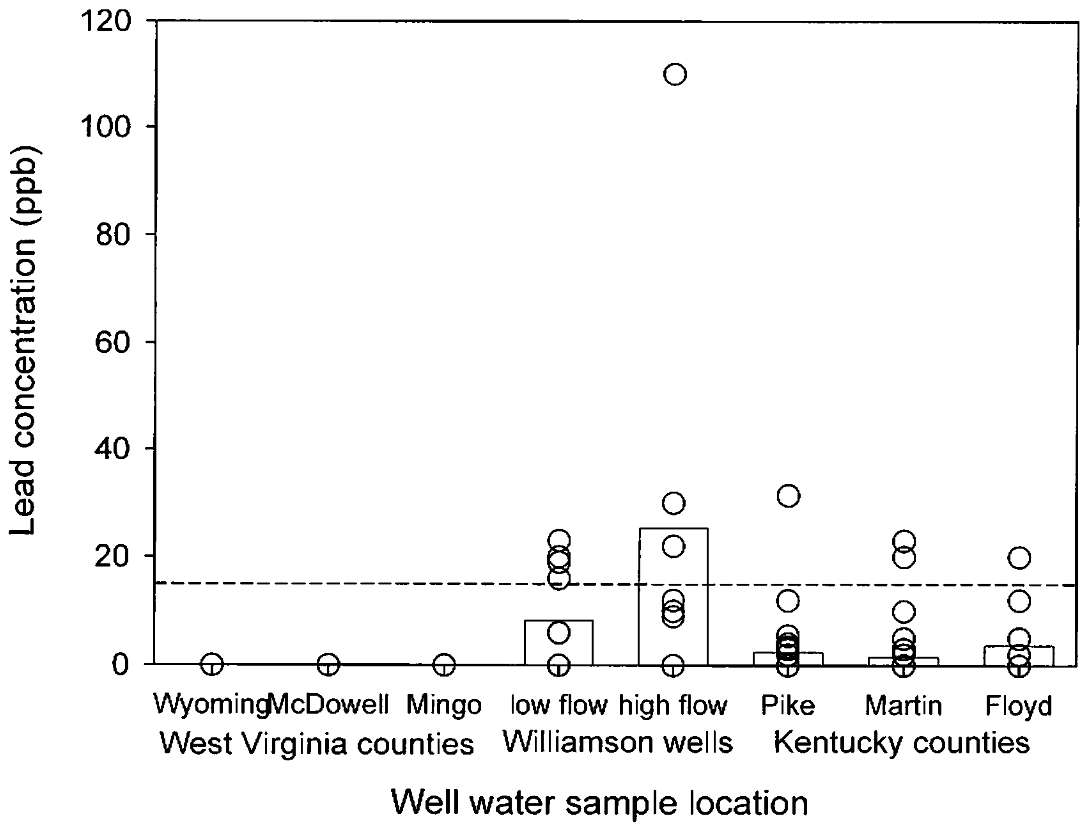
Williamson wells at high flow and the 3 McDowell County wells exceeded standards for iron and manganese 10% of the time. One Williamson area well that was sampled at both low and high flow, 2 Williamson area wells sampled only during high flow, 4 wells in Pike County, and 1 Martin County well had extremely high concentrations of iron and manganese. These values were nearly 10-times the standard.

Average sodium concentrations, while way above recommended standards, show an opposite pattern to the aforementioned metals. Sodium concentrations are lower in Williamson wells than in other regional wells. This may reflect cation exchange in the presence of metals. Regardless, sodium is consistently above standard in the majority of Williamson wells. High sodium levels in the presence of high metals concentrations is an additional health effects concern for Williamson area wells.

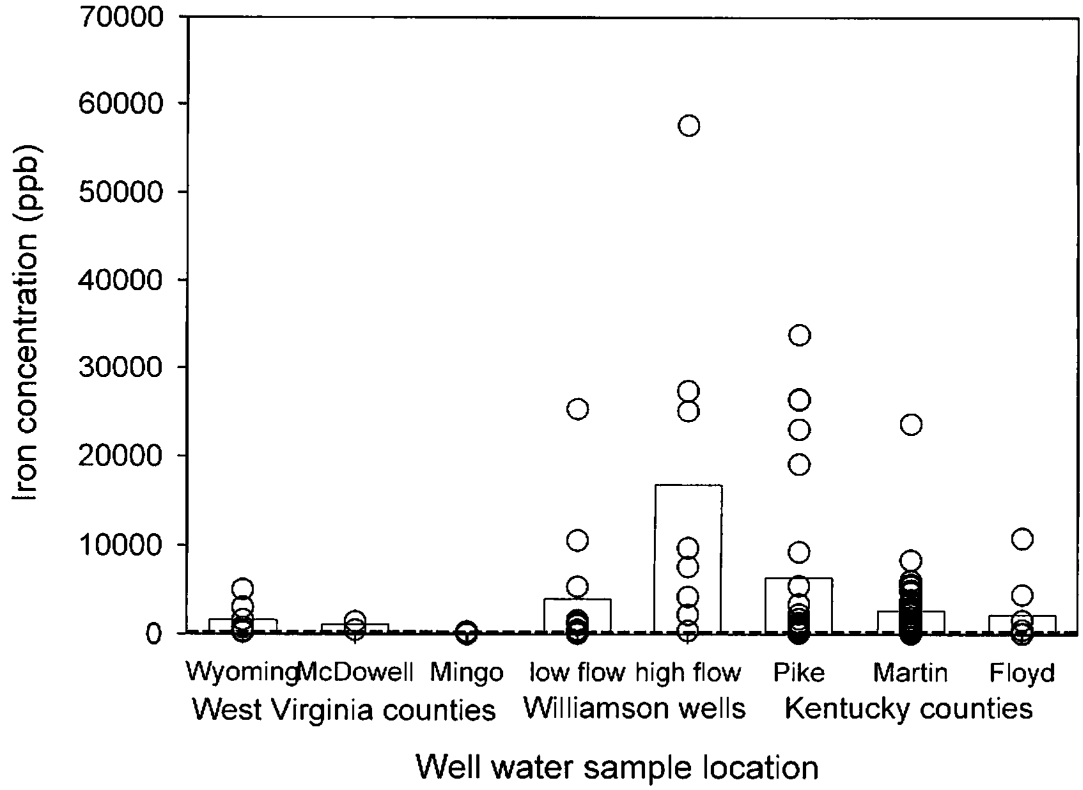
Table 4. Summary statistics for Williamson well samples compared to other regional well samples.

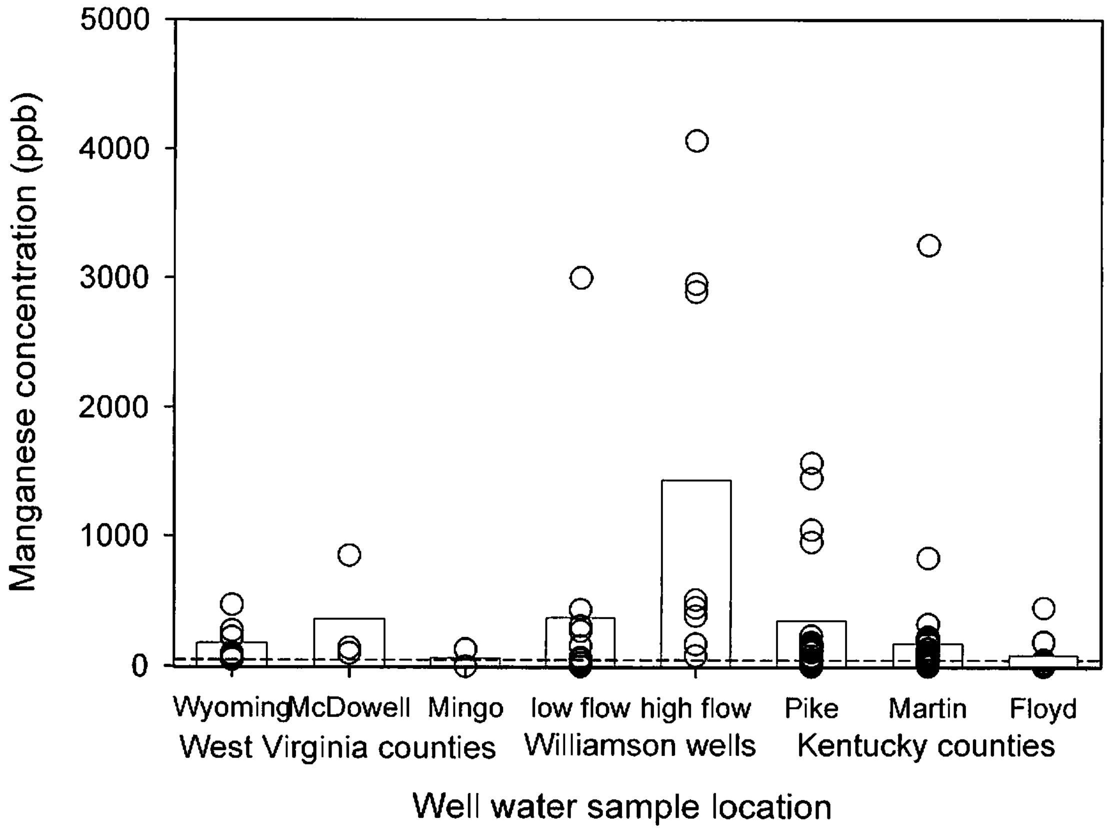
	West Virginia counties			Williamson wells		Kentucky counties		
Arsenic	Wyoming	McDowell	Mingo	low flow	high flow	Pike	Martin	Floyd
samples	7	3	2	12	8	23	45	11
%detect	0	0	0	8	75	13	22	0
%exceed	0	0	0	0	25	0	9	0
Lead								
samples	7	3	2	12	8	25	45	11
%detect	0	0	0	50	88	28	18	45
%exceed	0	0	0	42	38	4	4	9
Iron								
samples	7	3	2	12	8	25	45	8
%detect	10	10	50	10	10	10	10	10
%exceed	86	10	0	75	10	80	80	50
Manganese								
samples	7	3	2	12	8	25	45	11
%detect	10	10	50	92	10	96	10	82
%exceed	10	10	50	75	10	76	67	36
Sodium								
samples	7	3	2	12	8	23	45	15
%detect	10	10	10	10	10	10	10	10
%exceed	10	10	10	83	75	91	82	10





Figures 1 & 2. Arsenic and lead concentrations in Williamson area well water in relation to other regional well water samples. Concentrations below detection limits are shown as zero. Bars indicate average concentration in each group. Dashed line indicates drinking water standards. Samples sizes shown in Table 4.





Figures 3 & 4. Iron and manganese concentrations in Williamson area well water in relation to other regional well water samples. Concentrations below detection limits are shown as zero. Bars indicate average concentration in each group. Dashed line indicates drinking water standards. Samples sizes shown in Table 4.

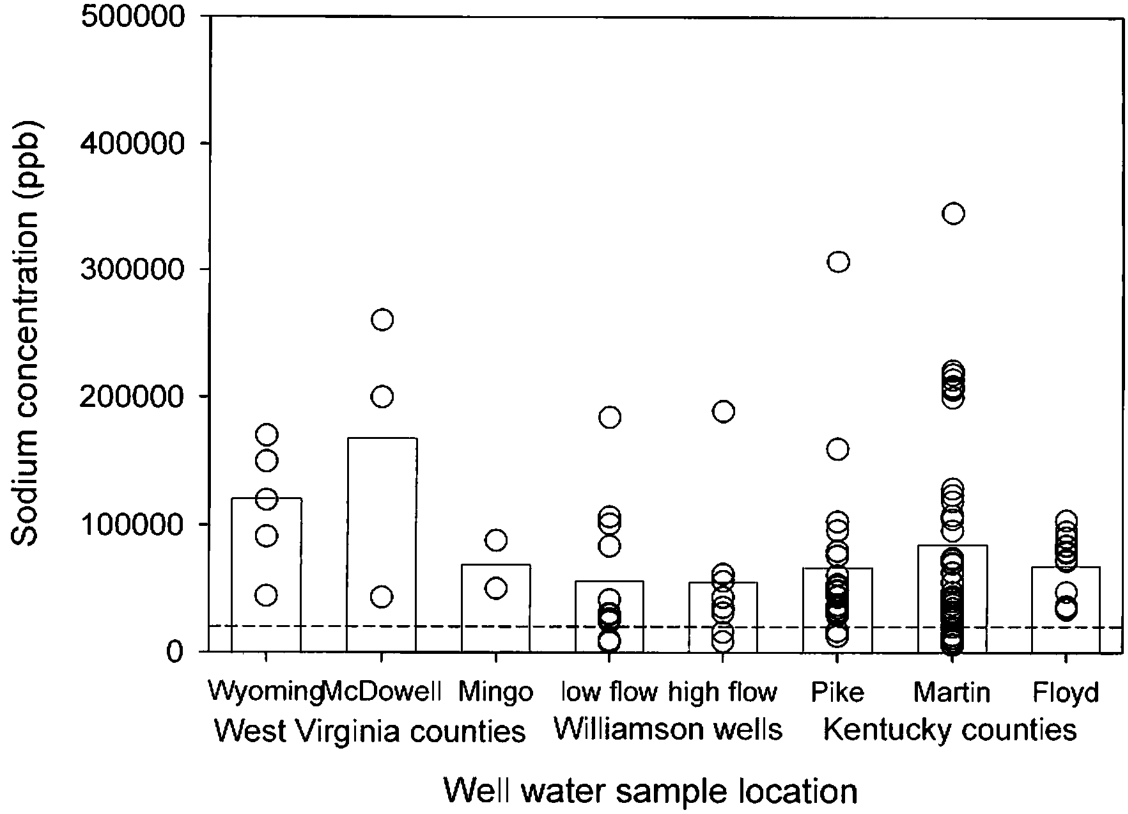


Figure 5. Sodium concentrations in Williamson area well water in relation to other regional well water samples. Concentrations below detection limits are shown as zero. Bars indicate average concentration in each group. Dashed line indicates drinking water standards. Samples sizes shown in Table 4.

Discussion

Water supply concerns

The results of this study indicate that well water quality in the area of Sprigg, Merrimac, Rawl, and Lick Creek near Williamson, West Virginia is unquestionably poor. Excessive levels of heavy metals, particularly lead and arsenic, may present a chronic health hazard to those families exposed to wells. Exposure may occur from inhalation and ingestion during bathing, using tap water in icemakers, and from contact with well water during washing in sinks, dishwashers and washing machines; particularly when hot water is used. Hot water heaters act to concentrate metals prior to delivery to the household system.

The metals found in Williamson area wells are commonly associated with coal mining activities, and these levels may be confounded by historic mining practices or exacerbated by recent drilling activities. However, iron at levels up to 57,588 ppb and manganese at levels up to 4,063 ppb indicates that Williamson area wells may be subjected to coal slurry contamination. Samples of coal slurry liquids collected in 1985 from the Pond Fork coal slurry impoundment yielded 3,833,000 ppb of iron and 20,000 ppb of manganese (US EPA, 1985). Likewise, slurry samples from the Big Branch Impoundment in Martin County, KY, had 10,700,000 ppb iron and 53,500 ppb manganese (US EPA, 2001).

Arsenic is common in coal and associated shale, and is adsorbed onto iron oxides and oxyhydroxides (Fisher, 2002). Iron hydroxide ($Fe(OH)_3$), commonly referred to as "yellow boy," is the most common form of iron in oxygenated water (Wetzel, 1975) and appears to be the primary cause of red staining on clothes and porcelain in the households visited during this study. The reddish sludge collected from the bottom of the hot water heater had 557,700 ppb iron and 150 ppb arsenic. The non-detects of arsenic under low flow conditions followed by detects in 3 of 5 wells during high flow may be related to the arsenic-iron flocculent complex in the study wells.

The levels of metals found in Williamson area wells are greater than metals found in water supply wells in neighboring counties in southern West Virginia and eastern Kentucky. Although there is very little domestic well data available in this region, several of the few wells that have been tested in Pike and Martin Counties, Kentucky are also of serious concern. Nonetheless, metals were detected and standards exceeded in a greater percentage of Williamson area wells than in other coalfield region wells. Arsenic concentrations greater than 10 ppb are rare in Kentucky groundwater (Fisher & Goodmann, 2002). The Williamson area wells studied rank among the poorest in the nation in terms of arsenic (Welch, *et al*, 2000).

Metal concentrations in Williamson area well water repeatedly violated US EPA standards developed for public water supply sources. While most of our samples were from private wells, only the spring, a dug well, and 5 of the 14 drilled wells tested appear to be reasonable sources of drinking water. Seven of 14 drilled wells exceeded primary drinking water standards. Thirteen of the 14 drilled wells exceeded secondary drinking water standards. Although secondary standards are considered to impart taste and odor concerns more so than health concerns, the concentrations witnessed in these wells was extraordinary. For instance, in one well iron was 192 times greater than the secondary standard. Another well had manganese at 81 times greater than the secondary standard.

Sources of contamination

A considerable amount of effort has been directed at assessing source water quality in the area. Well water quality analyses done by the E.L. Robinson Engineering Company for the West Virginia Department of Environmental Protection (WVDEP, 2001) concluded that "the only feasible and permanent solution to the water quality problem of the study area is an extension of the Mingo County PSD's water system." The study also concluded that "the interview and water analysis phases of this study indicated severe problems with ground water sources within the study area."

Nonetheless, the Agency for Toxic Substances and Disease Registry (ATSDR) in conducting a Public Health Consultation in the Lick Creek area concluded that sites studied, including the Rawl Sales and Processing mine site, are not a public health hazard (ATSDR, 2004). Concurrently, ATSDR recommended that a) persons drinking groundwater from this area should consult with a doctor to see if they should restrict manganese in their diets or from other sources, such as multivitamins or mineral supplements b) persons with liver or gastrointestinal disease should consult a doctor to see if they should avoid ingestion of water in this area, water that is high in manganese, and c) infants should not be fed dry formula mixed with groundwater that is high in manganese and/or sulfates. Interestingly, within that same report it is stated that "coal mining activities can add many minerals to the groundwater such as iron, manganese, and sulfur." High iron, manganese and sulfate levels have long been considered indicators of water pollution from mining; however, other metals regulated by primary drinking water standards are also associated with mining and drilling. No such heavy metal data was available for ATSDR review.

Coal slurry has been injected into deep mines in this area since the 1980s (ATSDR, 2004). A study conducted by the West Virginia Department of Environmental Protection indicated that some of the wells along lower Lick Creek may have residue from slurry injection (WV DEP, 1995). The ATSDR (2004) study stated that chemicals in the mine would be "diluted with mine water, and the longer the sludge is in the mine, the greater the potential for dilution." This may be so, but the "dilution effect", as evidenced by the new data presented herein, is still not enough to achieve water quality standards.

In their report ATSDR (2004) stated that "the nature of chemicals, if any, in the sludge that spilled into Lick Creek is unknown." While the chemical constituents of coal slurry certainly require further study (National Academy of Sciences, 2002), some data were available to ATSDR regarding the chemical composition of slurry. For instance, ATSDR was involved in a study regarding a 309 million gallon coal slurry spill at Martin County Coal Corporations Big Branch Impoundment near Inez, Kentucky in October, 2000. The ATSDR's final report, dated April 22, 2003, included data indicating that coal slurry solids contained arsenic at up to 8,000 ppb and lead at up to 21,000 ppb (ATSDR, 2003a). Moreover, a stream water sample collected in Coldwater Creek a week after the spill had 86 ppb arsenic and 430 ppb lead (US EPA, 2000). The administrative record

(US EPA, 2001) also contained slurry chemistry data that was collected by Eastern Coal Corporation as part of a consent order on a Superfund site near McAndrews, Kentucky, approximately 4 air miles south of Williamson (US EPA, 1985). Eastern Coal Corporation began underground injection of coal slurry into an abandoned mine in January, 1984. In November, 1984 citizens in the surrounding area complained of possible contamination of their water supply. In February, 1985 EPA ordered Eastern Coal Corporation to cease injecting slurry until it received an Underground Injection Control permit because "the slurry being injected by Eastern contained contaminants which were likely to enter a public water supply and may present an imminent and substantial endangerment to human health." The water from the coal slurry sample collected by Eastern contained, among other contaminants, 1,820 ppb arsenic and 3,890 ppb lead. In March, 1985 Eastern provided citizens with a connection to the water system to the Williamson, West Virginia water supply and Eastern was allowed to resume slurry injection (EPA, 1985).

Prior to the current study no arsenic testing had been done in the communities of Sprigg, Merrimac, Rawl, and Lick Creek. Although arsenic was mentioned in the ATSDR report in response to a claim of a poisoned child, the agency stated that no data could be obtained to assess this claim and that the child had moved away from the area. The ATSDR maintained that the exposure pathway no longer exists because 2 households that had used spring water are now supplied with well water. The conclusions of the report state that there is no apparent public health hazard with regard to possible contamination from 3 sites including the Rawl Sales and Processing strip mine (ATSDR, 2004). The results of the current study conflict with those findings. The ATSDR ranks arsenic and lead as the top 2 substances on their 2003 priority list (ATSDR, 2003). The priority list is a list of 275 substances commonly found at Superfund sites "which are determined to pose the most significant potential threat to human health due to their known or suspected toxicity and potential for human exposure" at Superfund sites on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) national priority list.

We recommend that ATSDR revisit the concerns of citizens regarding well water and health in the Williamson area. Additional well water testing should be conducted either by WV DEP or US EPA in support of a ATSDR health effects study. In addition to metals, a through analysis of volatile organic compounds, such as acrylamides and other additives used in the coal preparation process should be tested in order to identify source(s) of contamination. Should evidence of coal preparation residues mount, tracer dye, stable isotopes, or volatile organic chemicals unique to coal preparation plants could be measured to help identify the source(s) of contamination.

Conclusion

This study supports the claims of citizens that their well water is contaminated and subject to "blackwater" events. Well water often contained black particles and yielded metal concentrations in excess of drinking water standards. This confirms that the well water being utilized by citizens in the area is polluted. Additional studies are required to determine the exact source of contamination; however, our data suggest that coal-related activities may contribute to the pollution. Most of the households visited during the study reported health concerns related to water quality including kidney stones, cancers, and developmental issues regarding the young. Given the two-decade history of contaminated well water and associated health problems in the communities of Sprigg, Merrimac, Rawl, and Lick Creek, it is the opinion of the authors that a detailed, professionally administered study of the relationship between illness and well water quality should be conducted.

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Fw: FOIA
Ross Geredien to: Christopher Hunter 11/18/2011 10:25 AM

Ross Geredien
ORISE Fellow
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202-566-1466
Geredien.ross(AT)epa.gov

----- Forwarded by Ross Geredien/DC/USEPA/US on 11/18/2011 10:25 AM -----

From: "Hendryx, Michael" <mhendryx@hsc.wvu.edu>
To: Ross Geredien/DC/USEPA/US@EPA
Date: 08/18/2011 12:17 PM
Subject: RE: Additional Health Papers

Thanks very much. I had seen the Stout and Blakeney papers but the Wigginton paper is new. It was good to have a chance to speak with you all, and looking forward to future communications.

-----Original Message-----
From: Geredien.Ross@epamail.epa.gov [mailto:Geredien.Ross@epamail.epa.gov]
Sent: Thursday, August 18, 2011 11:23 AM
To: Hendryx, Michael
Subject: Additional Health Papers

Dr. Hendryx,

It was great to speak with you on the Conference Call yesterday. I am attaching two peer-reviewed papers that I think you will find very interesting with respect to health effects from mining in Appalachia.
These two papers are not typical epi studies, but they help fill an important gap in the health literature. The Blakeney paper is very unique in that it documents a number of psycho-social and occupational effects, incorporating anecdotal evidence using social survey methods.
The Wigginton paper points to possible vectors of exposure that have not been discussed. And although I'm sure you have it already, I've attached Ben Stout's 2004 report.

(See attached file: wju_report Ben Stoudt 2004.pdf)(See attached file: Blakeney and Marshall 2009.pdf)(See attached file: Wigginton et al 2007 Heavy Metals Water Tanks.pdf)

Ross Geredien
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Fw:FOIA
Ross Geredien to: Christopher Hunter 11/18/2011 10:41 AM

Obviously, you have this.

Ross Geredien
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----- Forwarded by Ross Geredien/DC/USEPA/US on 11/18/2011 10:41 AM -----

From: Christopher Hunter/DC/USEPA/US
To: Ross Geredien/DC/USEPA/US@EPA
Cc: Marcel Tchaou/DC/USEPA/US@EPA
Date: 08/17/2011 03:42 PM
Subject: Re: Meeting w/ Dr. Hendryx

Dave will be there, and Dr. Hendryx will be calling in.

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

Ross Geredien Who else is the audience, Chris? Will he be in p... 08/17/2011 03:36:04 PM

From: Ross Geredien/DC/USEPA/US
To: Marcel Tchaou/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA
Date: 08/17/2011 03:36 PM
Subject: Re: Meeting w/ Dr. Hendryx

Who else is the audience, Chris? Will he be in person, or are we just calling in to a larger room/meeting?

Ross Geredien
ORISE Fellow
Wetlands and Aquatic Resources Regulatory Branch
EPA Office of Wetlands, Oceans, and Watersheds
202-566-1466
Geredien.ross(AT)epa.gov

Marcel Tchaou Chris I mainly have questions. I am sure he will i... 08/17/2011 03:31:06 PM

From: Marcel Tchaou/DC/USEPA/US
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: "Ross Geredien" <Geredien.Ross@epamail.epa.gov>
Date: 08/17/2011 03:31 PM
Subject: Re: Meeting w/ Dr. Hendryx

Chris I mainly have questions. I am sure he will introduce his studies
1. One thing we want to know from Hendrix his basis for determining the population size to arrive at a conclusion
2. For a given health effects does he see a spatial difference and if yes, has he seen any correlations?
3. Can he give a detail on his survey or assessment methods
4. What does he consider to be the most critical health effect and what is the vector mode?

****
Marcel K. Tchaou, Ph.D., P.E., P.H.
Environmental Engineer
Wetlands & Aquatic Resources Regulatory Branch
Office of Wetlands, Oceans and Watersheds
U.S. EPA
1200 Pennsylvania Avenue, NW (MC 4502T)
Washington, DC 20460
202-566-1904

Christopher Hunter We don't really have an agenda, so if you have... 08/17/2011 03:15:59 PM

From: Christopher Hunter/DC/USEPA/US
To: "Ross Geredien" <Geredien.Ross@epamail.epa.gov>, "Marcel Tchaou" <Tchaou.Marcel@epamail.epa.gov>
Date: 08/17/2011 03:15 PM
Subject: Meeting w/ Dr. Hendryx

We don't really have an agenda, so if you have any ideas on discussion topics, let me know.
Thanks
Chris Hunter
Resources Regulatory Branch
Office of Water, US EPA
(202) 566-1454 (t)
(202) 573-6478 (c)

Re: meeting follow up
David Evans to: Hendryx, Michael 08/01/2011 11:25 AM
Cc: Christopher Hunter

Michael,

I'm checking in with my staff who work on the surface coal mining policy /project review front full time to get their ideas. I also think there would be value in holding a call with them, we likely likely suggest that. If there are days of the week that would be best to plan for (late this week would be soonest we'd be ready, probably better to plan out 1-2 weeks), let me know.

Very nice to meet you, and we are very interested in your work.

Dave

David Evans, Director
Wetlands Division
Office of Wetlands, Oceans and Watersheds
(202) 566-0535

RE: meeting follow up
Hendryx, Michael to: David Evans 08/01/2011 12:18 PM
Cc: Christopher Hunter

History: This message has been replied to.

Looking ahead to the next couple of weeks, next week good times for me are Aug 9 in the afternoon, or Aug 12 in the afternoon. The following week is pretty clear, about anytime except Monday the 15th should work.
Thanks
Mike

-----Original Message-----
From: David Evans [mailto:Evans.David@epamail.epa.gov]
Sent: Monday, August 01, 2011 11:25 AM
To: Hendryx, Michael
Cc: Christopher Hunter
Subject: Re: meeting follow up

Michael,

I'm checking in with my staff who work on the surface coal mining policy/project review front full time to get their ideas. I also think there would be value in holding a call with them, we likely likely suggest that. If there are days of the week that would be best to plan for (late this week would be soonest we'd be ready, probably better to plan out 1-2 weeks), let me know.

Very nice to meet you, and we are very interested in your work.

Dave

David Evans, Director
Wetlands Division
Office of Wetlands, Oceans and Watersheds
(202) 566-0535

RE: meeting follow up
Christopher Hunter to: Hendryx, Michael 08/01/2011 02:22 PM
Cc: David Evans

Hello Michael,
It looks like August 16 in the afternoon works well for both Dave and I. Is there a time that's good for you? I can sent up a meeting and conference call information to discuss.

Thanks

Chris Hunter
Acting Chief, Wetlands & Aquatic Resources Regulatory Branch
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

"Hendryx, Michael"	Looking ahead to the next couple of weeks, ne...	08/01/2011 12:18:05 PM

From: "Hendryx, Michael" <mhendryx@hsc.wvu.edu>
To: David Evans/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA
Date: 08/01/2011 12:18 PM
Subject: RE: meeting follow up

Looking ahead to the next couple of weeks, next week good times for me are Aug 9 in the afternoon, or Aug 12 in the afternoon. The following week is pretty clear, about anytime except Monday the 15th should work.
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-----Original Message-----
From: David Evans [mailto:Evans.David@epamail.epa.gov]
Sent: Monday, August 01, 2011 11:25 AM
To: Hendryx, Michael
Cc: Christopher Hunter
Subject: Re: meeting follow up

Michael,

I'm checking in with my staff who work on the surface coal mining policy/project review front full time to get their ideas. I also think there would be value in holding a call with them, we likely likely suggest that. If there are days of the week that would be best to plan for (late this week would be soonest we'd be ready, probably better to plan out 1-2 weeks), let me know.

Very nice to meet you, and we are very interested in your work.

Dave

David Evans, Director
Wetlands Division
Office of Wetlands, Oceans and Watersheds
(202) 566-0535

RE: meeting follow up
Christopher Hunter to: Hendryx, Michael 08/01/2011 02:53 PM
Cc: David Evans

Thanks,
I've sent an invitation for the 16th at 1pm. You can use my conference line at [redacted] and code [redacted]

I've also included the Section 404 mining team on the invitation and will talk to them in advance about topics.

Let me know if you have any questions,
Chris

Chris Hunter
U.S. Environmental Protection Agency
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(202) 566-1454
hunter.christopher@epa.gov

"Hendryx, Michael" How about 1 pm on the 16th? Thanks 08/01/2011 02:45:45 PM

From: "Hendryx, Michael" <mhendryx@hsc.wvu.edu>
To: Christopher Hunter/DC/USEPA/US@EPA
Cc: David Evans/DC/USEPA/US@EPA
Date: 08/01/2011 02:45 PM
Subject: RE: meeting follow up

How about 1 pm on the 16th?
Thanks

-----Original Message-----
From: Christopher Hunter [mailto:Hunter.Christopher@epamail.epa.gov]
Sent: Monday, August 01, 2011 2:22 PM
To: Hendryx, Michael
Cc: David Evans
Subject: RE: meeting follow up

Hello Michael,
It looks like August 16 in the afternoon works well for both Dave and I.
Is there a time that's good for you? I can sent up a meeting and
conference call information to discuss.

Thanks

Chris Hunter
Acting Chief, Wetlands & Aquatic Resources Regulatory Branch
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hunter.christopher@epa.gov

From: "Hendryx, Michael" <mhendryx@hsc.wvu.edu>

To: David Evans/DC/USEPA/US@EPA
Cc: Christopher Hunter/DC/USEPA/US@EPA
Date: 08/01/2011 12:18 PM
Subject: RE: meeting follow up

Looking ahead to the next couple of weeks, next week good times for me are Aug 9 in the afternoon, or Aug 12 in the afternoon. The following week is pretty clear, about anytime except Monday the 15th should work.

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Mike

-----Original Message-----
From: David Evans [mailto:Evans.David@epamail.epa.gov]
Sent: Monday, August 01, 2011 11:25 AM
To: Hendryx, Michael
Cc: Christopher Hunter
Subject: Re: meeting follow up

Michael,

I'm checking in with my staff who work on the surface coal mining policy/project review front full time to get their ideas. I also think there would be value in holding a call with them, we likely likely suggest that. If there are days of the week that would be best to plan for (late this week would be soonest we'd be ready, probably better to plan out 1-2 weeks), let me know.

Very nice to meet you, and we are very interested in your work.

Dave

David Evans, Director
Wetlands Division
Office of Wetlands, Oceans and Watersheds
(202) 566-0535

Meeting tomorrow - possible to reschedule
Christopher Hunter to: Hendryx, Michael 08/15/2011 03:01 PM

Hello Dr. Hendryx,
Dave Evans asked me to contact you to see if it would be possible to reschedule our meeting tomorrow to Wednesday at 4pm. If not, we can still meet tomorrow with staff from the Wetlands Division, but Dave Evans will not be able to attend. Please let me know if proposed time works for you, or if I don't hear from you we'll still hold the meeting at the same time via teleconference.

Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

RE: Meeting tomorrow - possible to reschedule
Hendryx, Michael to: Christopher Hunter 08/15/2011 04:13 PM
History: This message has been replied to.

It would be ok to change the time to 4 pm tomorrow. Please confirm if this change is made.
Thanks
Mike

Michael Hendryx, PhD
Associate Professor, Department of Community Medicine
Director, West Virginia Rural Health Research Center
West Virginia University
Morgantown, WV 26506
(304) 293-9206
mhendryx@hsc.wvu.edu

-----Original Message-----
From: Hunter.Christopher@epamail.epa.gov [
mailto:Hunter.Christopher@epamail.epa.gov]
Sent: Monday, August 15, 2011 3:01 PM
To: Hendryx, Michael
Subject: Meeting tomorrow - possible to reschedule

Hello Dr. Hendryx,
Dave Evans asked me to contact you to see if it would be possible to reschedule our meeting tomorrow to Wednesday at 4pm. If not, we can still meet tomorrow with staff from the Wetlands Division, but Dave Evans will not be able to attend. Please let me know if proposed time works for you, or if I don't hear from you we'll still hold the meeting at the same time via teleconference.

Thanks

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

RE: Meeting tomorrow - possible to reschedule

Christopher Hunter to: Hendryx, Michael 08/15/2011 04:27 PM

I've confirmed that Dave will be available Wednesday at 4, so let's plan on that. Thanks for your understanding.

Chris

Chris Hunter
U.S. Environmental Protection Agency
Office of Wetlands, Oceans, & Watershed
(202) 566-1454
hunter.christopher@epa.gov

"Hendryx, Michael" It would be ok to change the time to 4 pm tomor... 08/15/2011 04:13:38 PM

From: "Hendryx, Michael" <mhendryx@hsc.wvu.edu>
To: Christopher Hunter/DC/USEPA/US@EPA
Date: 08/15/2011 04:13 PM
Subject: RE: Meeting tomorrow - possible to reschedule

It would be ok to change the time to 4 pm tomorrow. Please confirm if this change is made.
Thanks
Mike

Michael Hendryx, PhD
Associate Professor, Department of Community Medicine
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Morgantown, WV 26506
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mhendryx@hsc.wvu.edu

-----Original Message-----
From: Hunter.Christopher@epamail.epa.gov [
mailto:Hunter.Christopher@epamail.epa.gov]
Sent: Monday, August 15, 2011 3:01 PM
To: Hendryx, Michael
Subject: Meeting tomorrow - possible to reschedule

Hello Dr. Hendryx,
Dave Evans asked me to contact you to see if it would be possible to reschedule our meeting tomorrow to Wednesday at 4pm. If not, we can still meet tomorrow with staff from the Wetlands Division, but Dave Evans will not be able to attend. Please let me know if proposed time works for you, or if I don't hear from you we'll still hold the meeting at the same time via teleconference.

Thanks

Chris Hunter
U.S. Environmental Protection Agency

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